U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-278 847

Regional Air Pollution Study Criteria and Non-Criteria Pollutant Source Testing Program

Rockwell International, Creve Coeur, Mo Air Monitoring Center

Prepared for

Environmental Sciences Research Lab, Research Triangle Park, N C

Nov 77

EPA-600/4-77-044
November 1977

PB 278 847

Environmental Monitoring Series

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL MONITORING series. This series describes research conducted to develop new or improved methods and instrumentation for the identification and quantification of environmental pollutants at the lowest conceivably significant concentrations. It also includes studies to determine the ambient concentrations of pollutants in the environment and/or the variance of pollutants as a function of time or meteorological factors.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/4-77-044

2.

3. RECIPIENT'S ACCESSION NO.
PB278847

4. TITLE AND SUBTITLE
REGIONAL AIR POLLUTION STUDY
Criteria and Non-criteria Pollutant Source Testing Program

5. REPORT DATE
November 1977

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
F.E. Littman, and O. Klein
R.W. Griscom,

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Rockwell International
Air Monitoring Center
11640 Administration Drive
Creve Coeur, MO 63141

10. PROGRAM ELEMENT NO.
1AA603 (AA-07(FY-77)

11. CONTRACT/GRANT NO.
68-02-2093
Task Order 108B

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Sciences Research Laboratory - RTP, N.C.
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/09

15. SUPPLEMENTARY NOTES

16. ABSTRACT

To enhance the accuracy of the emission inventory for the Regional Air Pollution Study (RAPS), a special emission factor development program was conducted in 1975 and 1976 on many of the large emission sources. Source testing of typical sources was carried out using standard EPA methods. Data for the criteria pollutants -- SO_2, NO_x, HC, CO, and particulate matter -- were obtained, as well as for H_2SO_4 mist and particle size distribution.

Results indicate good agreement between measured and calculated SO_2 values. Agreement of NO_x and particulate values between actual tests and results calculated using standard emission factors is variable. Actual values tend to be lower than calculated values, at least for large combustion sources. In all cases, however, the specific plant emission factors measured in the RAPS program are being used in the RAPS emission inventory, since this was the prime purpose of the source testing program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air Pollution *Emission *Sources *Measurement	St. Louis, MO	13B

18. DISTRIBUTION STATEMENT
RELEASE TO PUBLIC

19. SECURITY CLASS *(This Report)*
UNCLASSIFIED

20. SECURITY CLASS *(This page)*
UNCLASSIFIED

21. NO. OF PAGES
240

22. PRICE
PC A11 / MF A01

EPA Form 2220-1 (9-73)

ATTENTION

AS NOTED IN THE NTIS ANNOUNCEMENT,
PORTIONS OF THIS REPORT ARE NOT LEGIBLE.
HOWEVER, IT IS THE BEST REPRODUCTION
AVAILABLE FROM THE COPY SENT TO NTIS.

EPA-600/4-77-044
November 1977

REGIONAL AIR POLLUTION STUDY

Criteria and Non-Criteria Pollutant Source Testing Program

By

F.E. Littman
R.W. Griscom
O. Klein
Rockwell International
Air Monitoring Center
11640 Administration Drive
Creve Coeur, MO 63141

Contract 68-02-2093
Task Order 108B

Project Officer

Charles C. Masser
Office of Air Quality Planning and Standards
Office of Air and Water Management
U.S. Environmental Protection Agency
Research Triangle Park, N.C. 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORAOTRY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N.C. 27711

DISCLAIMER

This report has been reviewed by the Environmental Sciences Research Laboratory U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commerical products constitute endorsement or recommendation for use.

ABSTRACT

To enhance the accuracy of the emission inventory for the Regional Air Pollution Study (RAPS) a special emission factor development program has been conducted in 1975 and 1976 on many of the large emission sources. Source testing of typical sourcrs was carried out using standard EPA methods. Data for the criteria pollutants - SO_2, NO_x, HC, CO, and particulates --were obtained, as well as for H_2SO_4 mist and particle size distribution.

Results obtained in the course of this study indicate good agreement between measured and calculated SO_2 values. Agreements of NO_x and particulate values between actual tests and results calculated using standard emission factors (AP-42) is variable. Actual values tend to be lower than calculated ones, at least for large combutstion sources. In all cases, however, the specific plant emission factors measured in the RAPS program are being used in the RAPS emission inventory, since this was the prime purpose for the source testing program.

TABLE OF CONTENTS

1.0 SUMMARY 1

2.0 INTRODUCTION 2

3.0 EMISSION FACTOR VERIFICATION STUDIES 3

- 3.1 BACKGROUND 3
- 3.2 TEST METHODS 5
  - 3.2.1 VELOCITY MEASUREMENTS 5
  - 3.2.2 SULFURIC ACID MIST 8
  - 3.2.3 PARTICLE SIZE DISTRIBUTION 12

4.0 RESULTS AND DISCUSSION 16

- 4.1 COMPARISON OF EMISSION FACTORS 16
- 4.2 SULFURIC ACID MIST (SO_3) 18
- 4.3 PARTICLE SIZE DISTRIBUTION 21

5.0 CONCLUSION 22

6.0 REFERENCES 23

APPENDIX I EMISSION FACTOR CALCULATIONS 24

APPENDIX II SOURCE TEST REPORTS 41

- ALPHA PORTLAND CEMENT 42
- OWENS-ILLINOIS GLASS 109
- GENERAL MOTORS ASSEMBLY PLANT 156
- CHRYSLER MOTORS ASSEMBLY PLANT 189
- U.S.S. AGRI-CHEM PLANT 210

TABLES

PAGE

TABLE 1 COMPARISON OF MEASURED AND CALCULATED FLOWS 6

TABLE 2 COMPARISON OF SO_2 EMISSIONS BASED ON CALCULATED AND MEASURED FLOW RATES 8

TABLE 3 COMPARISON OF STANDARD AND EXPERIMENTAL EMISSION FACTORS 17

TABLE 4 SULFUR OXIDE ANALYSES AND RATIOS 20

TABLE 5 PARTICLE SIZE DISTRIBUTIONS 21

FIGURES

PAGE

FIGURE 1 SULFUR TRIOXIDE COLLECTOR 10

FIGURE 2 SULFURIC ACID MIST SAMPLING TRAIN 11

FIGURE 3 ANDERSEN STACK SAMPLER 14

FIGURE 4 PERCENTAGE CONVERSION OF SO_2 TO SO_3 IN UTILITY BOILERS 19

1.0 SUMMARY

Detailed emissions data from stationary point sources in the St. Louis Interstate AQCR have been gathered during 1975 and 1976. The data are based upon emission factors and consumption or process data. To enhance the accuracy of the emission inventory a special emission factor development program has been conducted in 1975 and 1976 on many of the large emission sources.

Source testing of typical sources was carried out using standard EPA methods. Data for the criteria pollutants - SO_2, NO_X, HC, CO, and particulates - were obtained, as well as for H_2SO_4 mist and particle size distribution. The complete results for the testing performed in 1976 are included in this report. The results for 1975 have been reported previously, but are also included in the report in summary form to provide a comprehensive overview of the special emission factor development effort.

Results obtained in the course of this study indicate good agreement between measured and calculated SO_2 values. Agreements of NO_X and particulate values between actual tests and results calculated using standard emission factors (AP-42) is variable. Actual values tend to be lower than calculated ones, at least for large combustion sources. In all cases, however, the specific plant emission factors measured in the RAPS program are being used in the RAPS emission inventory, since this was the prime purpose for the source testing program.

2.0 INTRODUCTION

This is the second report describing the special emission factor development study. The first report dealt with source testing conducted during 1975 (68-02-1081-T055). This report describes the source testing conducted during 1976, as well as a summary of the results obtained in 1975.

3.0 EMISSION FACTOR VERIFICATION STUDIES

3.1 BACKGROUND

Emission estimates are based on consumption or production figures from which emissions are calculated using an emission factor. Emission factors are averaged numbers relating emissions to consumption or process data. In some cases, the relationship is direct and relatively uncomplicated. For example, for every ton of bituminous coal burned, a total of 38$\underline{S}$ pounds of sulfur dioxide is produced, where $\underline{S}$ indicates the sulfur content of the fuel, on a weight percent basis. Thus, if a plant burns 100 tons of 3% sulfur coal per hour, it emits

$$100 \times 38 \times 3 = 11{,}400$$

11,400 lbs of SO_2 per hour. Since in this particular case the sulfur is contained in the fuel and is converted virtually completely (95%) to SO_2, the numbers resulting from the use of the emission factor are quite accurate and reliable.

If, on the other hand, we wish to determine the amount of oxides of nitrogen produced by the same operation, a somewhat different situation ensues. The emission factor for a boiler burning bituminous coal, as given in the EPA publication AP-42 "Compilation of Air Pollution Emission Factors", varies with both boiler type and size, from 6 to 55 lbs. of NO_X per ton of coal. This is because the factors affecting NO_X production include flame and furnace temperature, residence time of the combustion gases, rate of cooling, amount of excess air, as well as the amount of nitrogenous compounds in the fuel. Thus, the emission factor of 18, which is applicable to a pulverized coal boiler of this size, is an averaged value. Actual values may depart significantly from the numbers obtained by such a factor.

In order to improve the accuracy of the emission inventory gathered at St. Louis, a number of representative sources were sampled and their stack effluents analyzed. An attempt was made to encompass a wide variety of the larger point sources: large and medium sized power plants burning coal, fuel oil and gas; industrial boilers of different types and sizes; and industrial operations, such as catalyst recovery units in a petroleum refinery, and cement kilns, known or suspected of being major sources of pollution.

The following sources were sampled in 1975 and 1976:

- Illinois Power's Wood River Power Plant, Wood River, Illinois
  - Boiler No. 1, operated on gas
  - Boiler No. 1, operated on fuel oil
  - Boiler No. 4, operated on coal
- Highland Power Plant, Highland, Illinois
  - Boiler No. 3, operated on coal
- Stag Brewery, Belleville, Illinois
  - Boiler No.1, operated on coal
- General Motors Assembly Plant, St. Louis, Missouri
  - Boiler No. 2, operated on coal
- Amoco Refinery, Hartford, Illinois
  - Boiler No. 6, operated on oil and gas
  - Catalyst Regeneration Unit
- Chrysler Motors Assembly Plant, Fenton, Missouri
  - Boiler No. 1, operated on gas
- Owens - Illinois Glass Company, Alton, Illinois
  - "A" Glass Furnace, operated on gas
- Alpha Portand Cement Company, Affton, Missouri
  - Cement Kiln, wet process, coal-fired
- U.S.S. Agri-Chem, Crystal City, Missouri
  - Nitric Acid Production Unit
- General Motors Assembly Plant (Re-test), St. Louis, Missouri
  - Boiler No. 2, operated on coal

3.2 TEST METHODS

In general, the test methods specified in the Appendix of Part 60, CFR Title 40, "Standards of Performance for New Stationary Sources" were used. The methods include:

Method 1 - Sample and Velocity Traverses
2 - Determination of Stack Gas Velocity
3 - Gas Analysis of CO_2, Excess Air and Dry Molecular Weight
4 - Determination of Moisture in Stack Gases
5 - Determination of Particulate Emissions
6 - Determination of SO_2 Emissions
7 - Determination of Nitrogen Oxide Emissions
8 - Determination of Sulfuric Acid Mist Emissions

3.2.1 Velocity Measurements

Serious problems were encountered with stack gas velocity measurements using Method 2. Using mass balance methods as a check, it became apparent that the values obtained with an S-type Pitot tube, used in accordance with Method 2, were high by amounts ranging from 8 to 78 percent. Reproducibility was adequate, and repeated calibration of the Pitot tube indicated that correct readings were obtained. A careful check of the literature indicated that high readings had been observed by other investigators. Burton (1) indicated that values of 104 to 150% of the rated value can be obtained. Grove (2) presented data indicating that, (a) significant errors are always positive, and (b) they can be very large. The most common source of errors is due to cyclonic flow, unfortunately a fairly common occurrence in power plant stacks, where "double entry" stacks (two boilers feeding one stack) are frequently used.

A comparison of measured and calculated flows is shown in Table 1. The flow rate was calculated from known fuel consumption, fuel composition and excess air data.

TABLE 1 - COMPARISON OF MEASURED* AND CALCULATED** FLOWS

Location	Flow, SCFH Measured	 Calculated	% Δ
Wood River #1	10,086,750	8,237,263	+22.5
Wood River #4	17,981,280	13,089,200	+37.4
Highland Power	1,386,070	910,920	+52.2
Stag Brewery	1,394,990	782,900	+78.2
Monsanto	1,687,655	1,563,000	+ 8.0
General Motors	1,598,005	1,434,847	+11.4
Amoco	2,540,899	-	-

* Using S-type Pitot tube, EPA Method 2

** Based on stoichiometry and excess air

One way of ascertaining the correctness of the data is by comparing the mass flow of SO_2 calculated from fuel consumption and sulfur analysis of the fuel, on one hand, with the value obtained from stack gas flow and analysis, on the other. The former is calculated according to Equation 1

$$W_{SO_2} = W_c \times 38 \times S \quad , \qquad (1)$$

where

W_{SO_2} - weight of SO_2 produced, lbs/hr

W_c - weight of coal consumed, Tons/hr

S - % sulfur in coal, dry basis

This value should be equal to one obtained from Equation 2

$$W_{SO_2} = C_{SO_2} \times Q_S \quad , \qquad (2)$$

where

C_{SO_2} - Concentration of SO_2 in stack gas, lbs./SCF

Q_S - Stack gas flow rate, SCF/hr

For example, the flow rate for Boiler #4 at Wood River was calculated thusly:

Assumed combustion reactions:

(1) $C + O_2 \rightarrow CO_2$

(2) $2\ H_2 + O_2 \rightarrow 2\ H_2O$ Excluded from calculation for dry flue gas

(3) $S + O_2 \rightarrow SO_2$

(4) Oxidation reaction uncertain

Composition of Coal		Lb-mols/100 lbs Coal	Combustion Reaction	Oxygen Required for Combustion, mols
C	61.43%	5.12	(1)	5.12
H_2	4.38%	(2.19)	(2)	(1.09)
S	3.21%	0.10	(3)	0.10
O_2	9.67%	0.30		-.30
N_2	1.11%	0.04	(4)	-
H_2O (moisture)	11.82%	(0.66)	(2)	-
Ash	8.55%			
Chlorides	0.02%			
	100.19%			6.01 mols oxygen

Average Excess Air: 40% 2.40

Total 8.41

Corresponding Nitrogen @ 3.76 x O_2 31.77

Dry flue gases per 100 lbs. coal, lb-mols:

$CO_2 + SO_2 + O_2 + N_2$ + Air Nitrogen

5.12 + 0.10 + 2.40 + 0.04 + 31.77 = 39.43 lb-mols/100# coal

$$\text{lb-mols} \times 386\ \frac{\text{SCF}}{\text{lb-mol}} = \text{SCF}$$

39.43 x 386 = 15,220 SCF/100# coal

@ 43 tons coal/hr. = 13,089,200 SCFH

A comparison of results is shown in Table 2. As can be seen from Table 2, the values obtained using flow rates based on mass balance show a much better agreement with values obtained from emission factors, than those based on Pitot measurements.

TABLE 2 - COMPARISON OF SO_2 EMISSIONS BASED ON CALCULATED AND MEASURED FLOW RATES

Location	W_{SO_2} - Weight of SO_2 Produced, Based on		
	AP-42 Emission Factor	Mass Balance	Measured Gas Flow
Wood River #1 (oil)	153 lbs/hr	178 lbs/hr	217 lbs/hr
Wood River #4	5246	5104	7035
Highland Power	414	433	658
Stag Brewery	75	82	125
General Motors	479	472	546
Amoco (boiler)	309	-	320
(catalytic cracker)	708	-	354

For this reason, calculated flow rates were used whenever there was an indication of non-linear flow in the stack, as indicated by the fact that turning the Pitot tube 90° on axis did not give a zero reading on the manometer.

3.2.2 Sulfuric Acid Mist

An alternate method was used for determining sulfuric acid mist. The current standard method for SO_3 in stack gases is EPA Method 8 (CFR 40, 60.85, Appendix-Test Methods). In this method, the sample of stack gases is drawn through a series of impingers. The first impinger contains 100ml of 80% iso-propanol; the second and third 100ml of 3% hydrogen perioxide. There is a filter between the first and second impinger to retain entrained particulates. The contents of the impingers are analyzed for sulfate using the barium perchlorate-thorin method.

Recent work cast doubts on both accuracy and reproducibility of Method 8 (3). The method assumes that only SO_3 (sulfuric acid mist) will be retained in the first impinger and filter (both of which are analyzed together). However, Hillenbrand (4) found that substantial amounts of SO_2 are retained in the first impinger, some of which is subsequently oxidized to SO_3, thus contributing to high results. For this reason a different technique was used, which was first described by Goksøyr and Ross (5) and subsequently verified by Lisle and Sensenbaugh (6). The method is generally referred to as the Shell method, as it was developed in their laboratories. The method is based on the condensation of sulfuric acid mist at temperatures below its dew point (but above the dew point of the water) in a condenser backed up by a fritted glass filter (4) (Figure 1). The condensate is washed out and titrated.

Data presented in references 4 and 5 indicate that adsorption of SO_3 is essentially complete, repeatability is excellent, SO_2 in concentrations up to 2000 ppm does not interfere and a precision of $\pm$ 0.3 ppm of SO_3 can be readily attained.

The method was then evaluated in our laboratories. The results of the evaluation indicate an average 100.1 $\pm$ 6.5% recovery with no significant interference from any of the variables tested (7).

The gas sampling train consists of water-cooled coil condenser maintained below the dew point of sulfuric acid at 140°-194°F, followed by a fritted glass plate and chilled impingers containing an isopropanol and hydrogen peroxide mixture, followed by an impinger containing silica gel for drying. This setup is shown in Figure 2.

The condensed sulfuric acid mist in the coil condenser is water washed from the condenser. The final determination is made by titrating the solution with barium chloride, using a thorin indicator. Isopropanol is added to the solution to improve the rapidity with which the barium sulfate precipitates during titration.

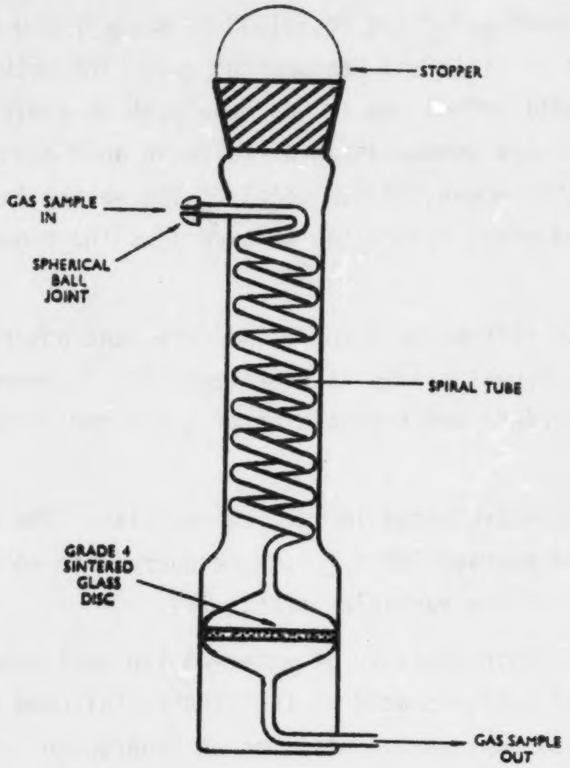

STOPPER
GAS SAMPLE IN
SPHERICAL BALL JOINT
SPIRAL TUBE
GRADE 4 SINTERED GLASS DISC
GAS SAMPLE OUT

FIGURE 1 - SULFUR TRIOXIDE COLLECTOR

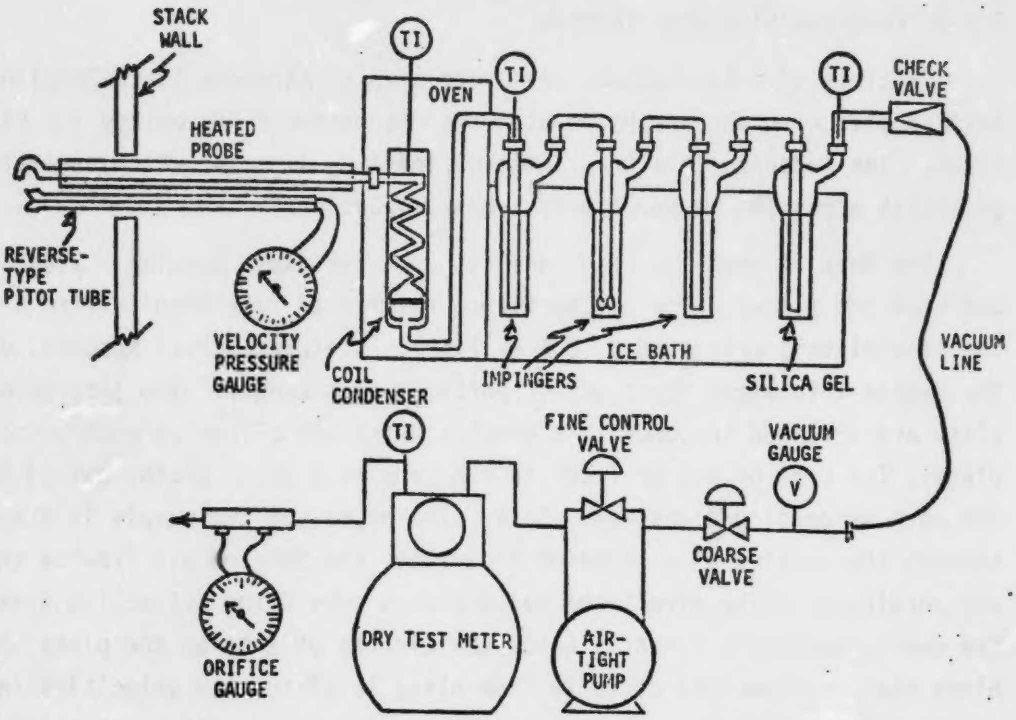

STACK WALL
TI
OVEN
TI
TI
CHECK VALVE
HEATED PROBE
REVERSE-TYPE PITOT TUBE
VELOCITY PRESSURE GAUGE
COIL CONDENSER
IMPINGERS
ICE BATH
SILICA GEL
VACUUM LINE
TI
FINE CONTROL VALVE
VACUUM GAUGE
V
COARSE VALVE
ORIFICE GAUGE
DRY TEST METER
AIR-TIGHT PUMP

FIGURE 2 - SULFURIC ACID MIST SAMPLING TRAIN

Sulfur dioxide in the gas sample is oxidized to sulfur trioxide in the impingers containing the hydrogen peroxide. Sulfur dioxide is then determined by titrating the hydrogen peroxide solution with barium chloride, using a thorin indicator.

The re-test at General Motors was performed to compare the results obtained with the Shell method and the results using EPA Method 8. In addition, the use of a glass probe versus a stainless steel probe and the use of a glass wool filter were evaluated during this same test.

3.2.3 Particle Size Distribution

Particle size testing was performed with an Andersen Stack Sampling head coupled with the apparatus used for the standard EPA method for particulates. The Andersen is a fractionating inertial impactor which separates particles according to aerodynamic characteristics.

The Mark II sampling head consists of a stainless housing plate holder and nine jet plates. The plates have a pattern of precision-drilled orifices. The nine plates, separated by 2.5 millimeter stainless steel spacers, divide the sample into eight fractions or particle size ranges. The jets on each plate are arranged in concentric circles which are offset on each succeeding plate. The size of the orifices is the same on a given plate, but is smaller for each succeeding downstream plate. Therefore, as the sample is drawn through the sampler at a constant flow rate, the jets of air flowing through any particular plate direct the particulates toward the collection area on the downstream plate directly below the circles of jets on the plate above. Since the jet diameters decrease from plate to plate, the velocities increase such that whenever the velocity imparted to a particle is sufficiently great, its inertia will overcome the aerodynamic drag of the turning airstream and the particle will be impacted on the collection surface.

The Mark III is identical to the Mark II except the location of the orifices in the plates have been modified to permit the use of a special collection substrate (glass fiber in our tests). This permits lighter tare weights for gravimetric analyses and a collection of material for chemical analysis. Figure 3 illustrates the Andersen sampling head and an exploded view of the plate holder and plates.

Particle size distribution measurements were made at seven of the test sites sampled. Initially only the Andersen Mark II plates were available. Because of this, the only results available at the first test site are the weight distribution. On subsequent tests, runs were made with both the Mark II plates and Mark III plates with glass fiber filters for comparison.

At General Motors, fourteen tests were performed to evaluate variations of testing methods consisting of placing the Andersen in-stack, out of stack (in oven), using Mark II plates and Mark III plates with filters. The main objective of these tests was to arrive at a testing arrangement to be used on all subsequent tests. However, there was no clearcut single method which proved better than the other. Each of these methods has its advantages which may make it desirable for any one individual test.

Sampling in the stack avoids any problems with extracting a sample and having some of it deposited in the probe. Also, the sample head is at the same temperature as the stack gases which avoids any problems of condensation. In-stack sampling, however, means the impaction surface is vertical and is subject to having the sample dislodged in handling. When sampling must be done vertically in a duct, from the top down, this method cannot be used.

Sampling with the Andersen sampler in the sample oven at the end of a heated probe affords much better handling. The sample head can be kept vertical with the plates horizontal at all times. The sample head can be clamped in place and not threaded on to the probe, thus avoiding more handling.

Isokinetic sampling rates can be determined more readily when the Andersen sampler is in the oven since the probe remains in the stack and has a Pitot attached. For in-stack sampling a Pitot measurement is made and the Pitot is removed. The sampler is then inserted to approximately the same position. There are two problems with sampling this way: (1) the oven can be heated only to 350°F, which may not be as high as the temperature in the stack; and (2) larger particles tend to be deposited in the probe, which lowers the weight of the deposit on the first two plates.

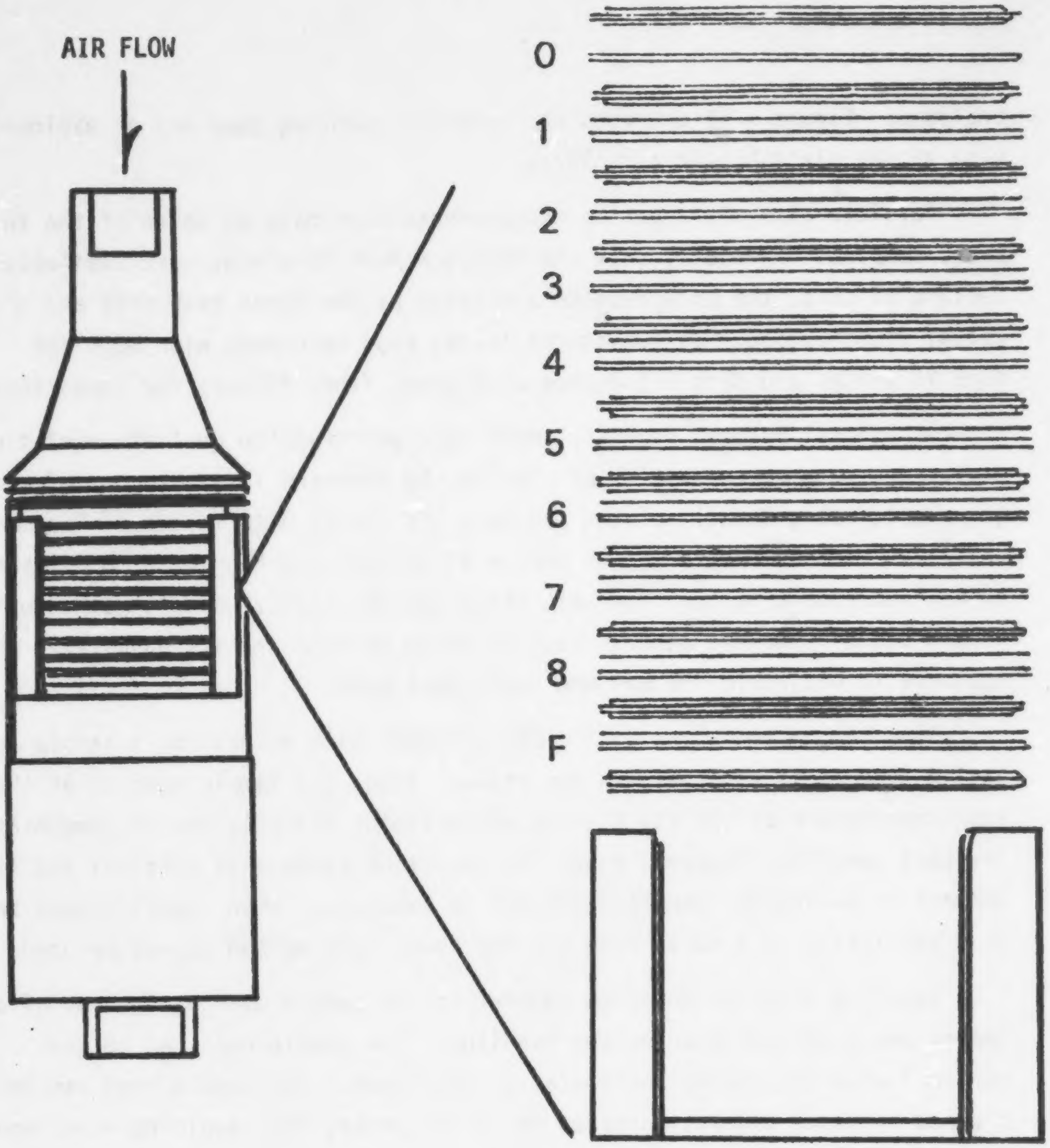

AIR FLOW
0
1
2
3
4
5
6
7
8
F

FIGURE 3 - ANDERSEN STACK SAMPLER

Parallel sampling with both the Mark II plates and the Mark III plates with filters indicated that there was no significant difference in the weight of sample obtained or the size distribution between these two methods. If the Mark II model is used, the number of tests is limited by how many sets of plates are available. With the Mark III plates and filters more runs can be performed by changing the filters between runs with the available time being the only constraint on the number of runs. More care must be taken in assembling the Mark III, since the filters are pre-cut to match the plates and must be properly aligned to avoid blocking any holes.

As a result of these comparison tests, it was decided that testing would be performed with the Mark III plates and filters and that the Andersen sample head would be placed in the oven for ease in handling and subsequent analysis.*

---

* For more details, see Reference 7.

4.0 RESULTS AND DISCUSSION

4.1 COMPARISON OF EMISSION FACTORS

Using the most reliable available results, experimental emission factors were calculated for SO_2, NO_X, CO, HC, and particulates for the sources tested. These emission factors are compared in Table 3 with the standard emission factors from AP-42. Calculations are shown in Appendix I.

Even though relatively few source tests have been run so far, certain conclusions can be drawn from the results obtained:

1. Determinations of stack gas volumes according to EPA Method 2 is uncertain. Incorrect results are obtained in a high number of cases, since the basic assumption of laminar flow, parallel to the walls of the stack, frequently does not occur.
2. Engineering calculations of mass flow, based on ultimate analysis of the fuel and determinations of the excess air in the stack gases, give reasonably accurate results. This is confirmed through sulfur balance calculations. For example, the average experimental emission factors for SO_2 for coal burning installations come out to $38.75\underline{S}$ compared with $38\underline{S}$ suggested in AP-42.
3. The emission factors in Table 3 are applicable only to the specific installations for which they were obtained. However, definite patterns appear to exist, which seem to have more general validity:
    a) Emission factors for NO_X for large combustion sources (utilities) appear to be too high by a variable, but substantial, margin. The experimentally obtained factors range from a low of 7.7% to 72% of the applicable AP-42 factors. For smaller sources good agreements were obtained.

TABLE 3 - COMPARISON OF AP-42 AND EXPERIMENTAL EMISSION FACTORS

		AP-42 EMISSION FACTORS					EXPERIMENTAL EMISSION FACTORS				
	SCC CODE(1)	SO_2	NO_X	PART	CO	HC	SO_2	NO_X	PART	CO	HC
Chrysler Motors - #1 (4)	10200601	-	230	-	-	-	-	235.5	-	-	-
Owens Ill.-"A" Glass Furnace(5)	30501401	-	-	2.00	-	-	2.2	552	0.58	-	-
Alpha Cement - Wet Process (6)	30500705	23.8	2.6	228	-	-	28.4	7.9	203	-	-
USS Agri Chem - HNO_3 Unit (7)	30101301	-	52.5	-	-	-	-	60.4	-	-	-
Wood River #1 (4)	10100601	-	600	10	17	1	-	105	-	2.8	-
Wood River #1 (8)	10100501	144S(2)	105	8	3	2	168S	16	1.0	0.4	0.17
Wood River #4 (9)	10100202	38S	18	17A(3)	1	0.3	37S	1.4	10.0A	-	0.02
Highland Power (9)	10100208	38S	15	5A	2	1	40S	4.1	0.4A	-	-
Stag Brewery (9)	10200208	38S	15	5A	2	1	46S	7.2	1.9A	0.3	0.14
General Motors - #2 (9)	10200209	38S	15	13A	2	1	37S	10.8	23.6A	0.7	0.03
Amoco Cat Cracker Recovery (10)	30600201	439	71	242	-	220	246	153	360	-	0.48

(1) - The Source Classification Code and associated emission factors can be found in Appendix C of AP-42

(2) - S is the percentage sulfur in fuel

(3) - A is the percentage ash in fuel; emissions before control equipment

(4) - gas fired - lbs. per 10^6 cu. ft.

(5) - gas fired - lbs. per ton glass produced

(6) - coal fired - lbs. per ton cement produced

(7) - lbs. per ton 100% acid produced

(8) - oil fired - lbs. per 10^3 gal.

(9) - coal fired - lbs. per ton of coal

(10) - lbs. per 10^3 bbl fresh feed

b) Experimental emission factors for particulates similarly vary from 8 to 58% of the applicable AP-42 factors for installations which do not have precipitators. In the presence of the latter, their assumed efficiency becomes the determining factor.

c) Hydrocarbon and CO emissions, which are rather insignificant for combustion sources, have also been found to be less than those suggested by the AP-42 factors.

4.2 SULFURIC ACID MIST (SO_3)

The SO_3 concentrations of large and small boilers were investigated first. The concentrations ranged from 2.7 to 44.3 ppm, well within the range indicated by other investigators. As indicated in Figure 4, there appears to be a marked dependence on excess oxygen. The percentage of SO_3 increased with increasing oxygen up to about 9%, then dropped rapidly. This may be due to the cooling effect of large amounts of excess air. There did not seem to be any correlation with the sulfur content of the fuel nor did there appear to be any marked effect of boiler capacity on the amount of concentration of SO_3 produced. Data are presented in Table 4.

The RMS average SO_3 emission appears to be about 1.85% of the SO_2 emission. This factor will be incorporated in the data handling system output program, which will report SO_3 emissions based on the corresponding SO_2 emissions. Using the current figures for SO_2, this amounts to an annual emission of 22,585 tons of SO_3 per year for the St. Louis AQCR.

A second test at the General Motors Assembly Plant was conducted to study different sampling procedures and to compare the results using the Shell method and the EPA Method 8. The results of this testing are somewhat inconclusive but indicate that both methods give similar results. The data are shown in a report included in Appendix II.

With the exception of the source test at Alpha Portland Cement all tests for sulfuric acid mist were made using the Shell method described in section 3.3.1 of this report.

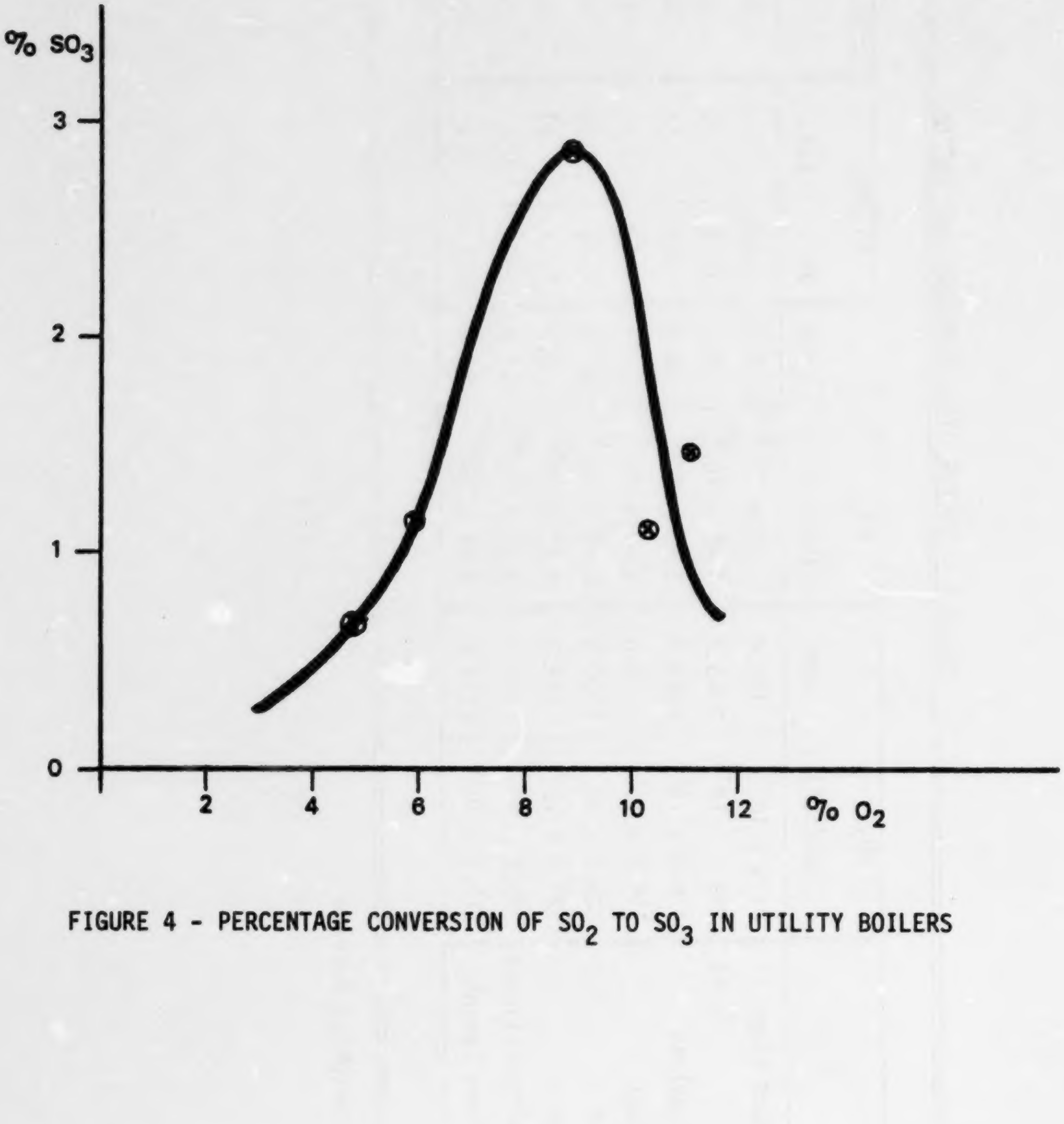


FIGURE 4 - PERCENTAGE CONVERSION OF SO_2 TO SO_3 IN UTILITY BOILERS

TABLE 4 - SULFUR OXIDE ANALYSES AND RATIOS

	SO_2 (lbs/SCF)	SO_2 ppm	SO_3 (lbs/SCF)	SO_3 ppm	SO_3/SO_2 Wt.	SO_3/SO_2 Vol.	Excess O_2	Boiler Cap lbs steam/hr	% Sulfur in Fuel
Wood River #1	21.5×10^{-6}	129.4	$.60 \times 10^{-6}$	2.9	2.82%	2.24%	8.9%	450,000	.29
#4	389.5×10^{-6}	2343.7	3.45×10^{-6}	16.6	1.13	.70	6.0	710,700	3.21
Highland	475.0×10^{-6}	2858.2	3.28×10^{-6}	15.8	.69	.55	4.8	60,000	3.25
Stag	119.0×10^{-6}	716.0	1.67×10^{-6}	8.1	1.41	1.12	11.2	50,000	3.25
GM	349.0×10^{-6}	2100.0	9.89×10^{-6}	47.6	2.83	2.26	8.9	80,000	3.46
Amoco	126.0×10^{-6}	758.2	1.42×10^{-6}	6.9	1.13	.91	10.5	200,000	*3.00
Owens-Illinois	30.0×10^{-6}	180.5	3.40×10^{-6}	16.4	11.3	9.1	8.0	--	--
Alpha Cement	211.7×10^{-6}	1273.8	3.07×10^{-6}	14.8	1.5	1.2	3.0	--	--

* Weighted Average

Results obtained on sampling modifications indicated that a short, glass-lined probe should be used whenever possible and a glass wool filter plug should be inserted in the probe just after the nozzle to remove any gross amount of particulates which would interfere with the determination.

4.3 PARTICLE SIZE DISTRIBUTION

This testing for particle size is also a continuation of work conducted in 1975 and reported in the EPA report on Sulfur Compounds and Particle Size (68-02-1081-T056) (7). A summary of the results of the testing is given in Table 5. Particle size is given as aerodynamic size for spherical particles with unit density.

TABLE 5 - PARTICLE SIZE DISTRIBUTIONS

Source	SCC Code	% vs Particle Size				
		>7µ	3-7µ	1-3µ	0.5-1µ	<0.5µ
Ill. Power - Wood River	1-01-002-02	22.5	22.8	18.5	8.3	27.9
Highland Electric	1-01-002-08	26.6	18.9	10.0	12.7	31.8
Stag Brewery	1-02-002-05	37.4	16.0	7.6	18.3	20.7
General Motors	1-02-002-09	14.3	24.4	18.5	9.2	33.6
Amoco	3-06-001-02 3-06-001-03	13.9	8.9	22.0	18.8	36.4
Owens Illinois	3-05-014-01	5.0	6.9	20.2	29.9	10.0
Alpha Cement	3-05-007-05	29.0	38.4	14.2	8.4	10.0

As with other sources tested, the measurements at Alpha Cement indicate a bimodal distribution, one peak at 3-7 micron and the other at less than 1 micron. The test at Owens - Illinois, however, indicated a single peak at approximately 1µ. The results are detailed in Appendix II.

5.0 CONCLUSIONS

The RAPS Point Source Emission Inventory has produced an extensive and accurate data base. Emission data for the base years of 1975 and 1976, with a temporal resolution of 1 hour for the criteria pollutants are available from the RAPS program.

The special emission factor development program, though somewhat limited in scope, has improved the emission inventory for many of the major point sources. Special emission factors were developed for a utility burning coal, oil, and gas, several industrial boilers burning coal, oil and gas, a cement kiln, a glass furnace, a nitric acid plant, and a catalytic cracker. In all, eleven sources were tested. The number of sources was limited by the problem of obtaining permission to test stacks. The percentage of total emissions in the AQCR represented by these tests are: 2.1% for SO_2, 1.3% for NO_X, 1.2% for particulates, and less than 0.1% for HC and CO.

6.0 REFERENCES

1. Burton, C. S., "Quantitation of Stack Gas Flow", J. Air Poll. Control Assoc. 22, 631 (1972).
2. Grove, D. J. and Smith, W. S., "Pitot Tube Errors Due to Misalignment and Non-streamlined Flow", Stack Sampling News, 1974.
3. Hamil, H. F., et al, "Collaborative Study of EPA Method 8 (Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions from Stationary Sources)", EPA 650/4-75-003.
4. Hillenbrand, et al, "Chemical Composition of Particulate Air Pollutants from Fossil-Fuel Combustion Sources", Battelle Columbus Labs, March 1973, EPA-R2-73-216, PB219.009.
5. Goksøyr, H., and K. Ross, "Determination of Sulphur Trioxide in Flue Gases", J. Inst. Fuel 35, 177 (1962).
6. Lisle, E. S. and J. D. Sensenbaugh, "Determination of Sulfur Trioxide and Acid Dew Point in Flue Gases", Combustion 36, 12, (1965).
7. Littman, F. E., et al, "Sulfur Compounds and Particulate Size Distribution Inventory", Rockwell International, Contract No. 68-02-1081-T056.

APPENDIX I

EMISSION FACTOR CALCULATIONS

New emission factors have been calculated for each source tested under this program. These factors only apply to these sources and not the general category indicated by the associated SCC code.

The information and calculation for each source that follows begin with the operating conditions of the source being tested and the fuel composition.

The experimental emission factor (EMFAC) is determined by first calculating the expected emissions using the emission factors from AP-42 and then comparing this number with the actual emissions determined from the source test. The AP-42 factor is then changed for this source in the ratio of the actual emission versus the expected emissions.

ILLINOIS POWER COMPANY
Wood River Power Plant
Boiler #1 - Gas Fired
SCC: 10100601

Burn Rate: 580×10^3 standard cubic feet/hour (SCF/hr)
Sulfur: -
Ash: -
Stack Flow Rate: 8,237,280 SCF/hr

$\underline{NO}_X$ AP-42 Factor: 600 lbs NO_X/million cubic feet of gas

Expected: $.580\ \overline{M}CF/hr \times 600 = 348$ lbs/hr

Found: 7.4×10^{-6} lbs NO_X/SCF $\times$ 8,237,280 = 60.9 lbs/hr

Experimental EMFAC: $600 \times \frac{60.9}{348} = 105 \ \frac{\text{lbs } NO_X}{\overline{M}CF \text{ gas}}$

CO AP-42 Factor: 17 lbs CO/$\overline{M}$CF gas

Expected: $.580\ \overline{M}CF/hr \times 17 = 9.9$ lbs/hr

Found: 2.5 ppm CO

$$2.5 \times 10^{-6} \times 8{,}237{,}280 \times 28 \ \frac{lb}{mol} \times \frac{1}{359} \ \frac{mol}{SCF} = 1.6 \text{ lbs/hr}$$

Experimental EMFAC: $17 \times \frac{1.6}{9.9} = 2.76 \ \frac{\text{lbs CO}}{\overline{M}CF \text{ gas}}$

ILLINOIS POWER COMPANY
Wood River Power Plant
Boiler #1 - Oil Fired
SCC: 10100501

Burn Rate: 3.66×10^3 gal/hr
Sulfur: 0.29%
Ash: -
Stack Flow Rate: 8,237,263 SCF/hr

$\underline{SO_2}$ NEDS Emission Factor: 144S lbs $SO_2/10^3$ gal oil

Expected: $3.66 \frac{10^3 \text{ gal}}{\text{hr}} \times 144 \times 0.29\%S = 152.8$ lbs/hr

Found: 178.0 lbs/hr

Experimental EMFAC: $144 \times \frac{178}{152.8} = 167.7 \times S \frac{\text{lbs } SO_2}{10^3 \text{ gal}}$

$\underline{NO_X}$ NEDS Emission Factor: 105 lbs $NO_X/10^3$ gal oil

Expected: $3.66 \times 105 = 384.3$ lbs/hr

Found: 7.1×10^{-6} lbs/SCF x 8,237,263 SCF/hr = 58.5 lbs/hr

Experimental EMFAC: $105 \times \frac{58.5}{384.3} = 16.0$ lbs $NO_X/10^3$ gal oil

$\underline{CO}$ NEDS Emission Factor: 3 lbs $CO/10^3$ gal oil

Expected: $3.66 \times 3 = 11.0$ lbs/hr

Found: 2.5 ppm CO

$$2.5 \times 10^{-6} \times 8{,}237{,}263 \times 28 \frac{\text{lb}}{\text{mol}} \times \frac{1}{359} \frac{\text{mol}}{\text{SCF}} = 1.6 \text{ lbs/hr}$$

Experimental EMFAC: $3 \times \frac{1.6}{11.0} = 0.44$ lbs $CO/10^3$ gal

PARTICULATES

NEDS Emission Factor: 8 lbs particulates/10^3 gal oil

Expected: $3.66 \times 8 = 29.3$ lbs/hr

Found: 4.55×10^{-7} lbs/SCF x 8,237,263 = 2.7 lbs/hr

Experimental EMFAC: $8 \times \frac{3.7}{29.3} = 1.0$ lbs part./10^3 gal oil

HYDROCARBONS

NEDS Emission Factor: 2 lbs HC/10^3 gal oil

Expected: $3.66 \times 2 = 7.3$ lbs/hr

Found: 1.7 ppm as CH_4

$$1.7 \times 10^{-6} \times 8{,}237{,}263 \times 16 \,\frac{\text{lb}}{\text{mol}} \times \frac{1}{359}\,\frac{\text{mol}}{\text{SCF}} = 0.64 \text{ lbs/hr}$$

Experimental EMFAC: $2 \times \frac{.64}{7.3} = 0.17$ lbs HC/10^3 gal oil

ILLINOIS POWER COMPANY
Wood River Power Plant
Boiler #4 - Coal Fired
SCC: 10100202

Burn Rate: 43 ton/hr
Sulfur: 3.21%
Ash: 10.95%
Stack Flow Rate: 13,089,200 SCF/hr
Precipitator Efficiency: 99.5%

$\underline{SO_2}$ AP-42 Factor: 38 x S lbs SO_2/ton coal

Expected: 43 ton/hr x 38 x 3.21%S = 5245 lbs/hr

Found: 5104 lbs/hr

Experimental EMFAC: $38 \times \frac{5104}{5245} = 36.97 \times S$ lbs SO_2/ton coal

$\underline{NO_X}$ AP-42 Factor: 18 lbs NO_X/ton coal

Expected: 43 x 18 = 774 lbs/hr

Found: 4.46×10^{-6} lbs/SCF x 13,089,200 = 58.4 lbs/hr

Experimental EMFAC: $18 \times \frac{58.4}{774} = 1.36$ lbs NO_X/ton coal

PARTICULATES

AP-42 Factor: 17 x A lbs part./ton coal

Expected: 43 x 17 x 10.95% Ash x (1-.995) = 40 lbs/hr

Found: 23.45 lbs/hr

Experimental EMFAC: $17 \times \frac{23.5}{40} = 9.96 \times A$ lbs part./ton coal

HYDROCARBONS

AP-42 Factor: 0.3 lbs HC/ton coal

Expected: 43 x 0.3 = 12.9 lbs/hr

Found: 1.3 ppm as CH_4

$$1.3 \times 10^{-6} \times 13{,}089{,}200 \times 16 \frac{\text{lb}}{\text{mol}} \times \frac{1}{359} \frac{\text{mol}}{\text{SCF}} = 0.76 \text{ lbs/hr}$$

Experimental EMFAC: $0.3 \times \frac{.76}{12.9} =$ 0.018 lbs HC/ton coal

HIGHLAND POWER COMPANY
Boiler #3 - Coal Fired
SCC: 10100208

Burn Rate: 6702 lbs coal/hr
Sulfur: 3.25%
Ash: 10.95%
Stack Flow Rate: 910,920 SCF/hr

$\underline{SO_2}$ AP-42 Factor: 38 x S lbs SO_2/ton coal

Expected: 6702 ÷ 2000 x 38 x 3.25% = 414 lbs/hr

Found: 433 lbs/hr

Experimental EMFAC: $38 \times \frac{433}{414} = 39.7 \times S$ lbs SO_2/ton coal

$\underline{NO_X}$ AP-42 Factor: 15 lbs NO_X/ton coal

Expected: 6702 ÷ 2000 x 15 = 50.3 lb/hr

Found: 1.5×10^{-5} lbs/SCF x 910,920 SCF/hr = 13.7 lbs/hr

Experimental EMFAC: $15 \times \frac{13.7}{50.3} = 4.1$ lbs NO_X/ton coal

PARTICULATES

AP-42 Factor: 5 x A lbs. part./ton coal

Expected: 6702 ÷ 2000 x 5 x 10.95% = 183.5 lbs/hr

Found: 1.76×10^{-5} lbs/SCF x 910,920 SCF/hr = 16 lbs/hr

Experimental EMFAC: $5 \times \frac{16}{183.5} = 0.44$ lbs. part./ton coal

STAG BREWERY
Boiler #1 - Coal Fired
SCC: 10200205

Burn Rate: 3604 lbs/hr
3895 lbs/hr (for SO_2 determination)
Sulfur: 1.04%
Ash: 10.98%
Stack Flow Rate: 782,900 SCF/hr

$\underline{SO_2}$ AP-42 Factor: 38 x S lbs. SO_2/ton coal

Expected: 3895 ÷ 2000 x 38 x 1.04 = 77.0 lbs/hr

Found: 1.244×10^{-4} lbs/SCF x 756,295 SCF/hr = 94.1 lbs/hr

Experimental EMFAC: $38 \times \frac{94.1}{77.0} = 46.4$ lbs SO_2/ton coal

$\underline{NO_X}$ AP-42 Factor: 15 lbs NO_X/ton coal

Expected: 3604 ÷ 2000 x 15 = 27.0 lbs/hr

Found: $1.65 \times 10^{-5} \times 782{,}900 = 12.9$ lbs/hr

Experimental EMFAC: $15 \times \frac{12.9}{27.0} = 7.16$ lbs NO_X/ton coal

CO AP-42 Factor: 2 lbs CO/ton coal

Expected: 3604 ÷ 2000 x 2 = 3.6 lbs/hr

Found: 8.9 ppm

$8.9 \times 10^{-6} \times 782{,}900 \times \frac{28}{359} = 0.54$ lbs/hr

Experimental EMFAC = $2 \times \frac{.54}{3.6} = 0.30$ lbs CO/ton coal

PARTICULATES

AP-42 Factor: 5 x A lbs part./ton coal

Expected: 3604 ÷ 2000 x 5 x 10.98 = 98.9 lbs/hr

Found 37 lbs/hr

Experimental EMFAC: $5 \times \frac{37}{98.9} = 1.87$ lbs part./ton coal

HYDROCARBONS

AP-42 Factor: 1 lbs HC/ton coal

Expected: $3604 \div 2000 \times 1 = 1.8$ lbs/hr

Found: 7 ppm as CH_4

$$7 \times 10^{-6} \times 782{,}900 \times \frac{16}{359} = 0.24 \text{ lbs/hr}$$

Experimental EMFAC: $1 \times \frac{0.24}{1.8} = 0.14$ lbs HC/ton coal

GENERAL MOTORS
Boiler #2 - Coal Fired
SCC: 10200209

Burn Rate: 7491 lbs/hr (for NO_X and Particulates)
7269 lbs/hr (for SO_2 determination)
Sulfur: 3.47%
Ash: 10.9%
Stack Flow Rate: 1,434,847 SCF/hr
Precipitator Efficiency: 98%

SO_2 AP-42 Factor: 38 x S lbs SO_2/ton coal

Expected: 7269 ÷ 2000 x 38 x 3.47% = 479 lbs/hr

Found: 472 lbs/hr

Experimental EMFAC: $38 \times \frac{472}{479} = 37.4 \times S$ lbs SO_2/ton coal

NO_X AP-42 Factor: 15 lbs NO_X/ton coal

Expected: 7491 ÷ 2000 x 15 = 56.2 lbs/hr

Found: 2.81×10^{-5} lb/SCF x 1,434,847 SCF/hr = 40.3 lbs/hr

Experimental EMFAC: $15 \times \frac{40.3}{56.2}$ = 10.8 lbs NO_X/ton coal

CO AP-42 Factor: 2 lbs CO/ton coal

Expected: 7491 ÷ 2000 x 2 = 7.5 lbs/hr

Found: 25 ppm

$$25 \times 10^{-6} \times 1{,}434{,}847 \text{ SCF/hr} \times \frac{28}{359} \times \frac{\text{lb}}{\text{lb mol}} \times \frac{\text{lb mol}}{\text{SCF}}$$

$$= 2.8 \text{ lbs/hr}$$

Experimental EMFAC: $2 \times \frac{2.8}{7.5}$ = .74 lbs CO/ton coal

PARTICULATES

AP-42 Factor: 13 x A lbs part./ton coal

Expected: $7491 \div 2000 \times 13 \times 10.9\% \times (1-.98) = 11$ lbs/hr

Found: 1.396×10^{-5} lbs/SCF x 1,434,847 SCF/hr = 20.0 lbs.hr

Experimental EMFAC: $13 \times \frac{20}{11} = 23.6 \times A$ lbs part./ton coal

HYDROCARBONS

AP-42 Factor: 1 lb HC/ton coal

Expected: $7491 \div 2000 \times 1 = 3.8$ lbs/hr

Found: 1.8 ppm as CH_4

$$1.8 \times 10^{-6} \times 1{,}434{,}847 \times \frac{16}{359} = .11 \text{ lbs/hr}$$

Experimental EMFAC: $1 \times \frac{.11}{3.8} = .03$ lbs HC/ton coal

AMOCO OIL REFINERY
Boiler #6 - Oil and Process Gas Fired
SCC: 30600103
30600108

Burn Rate: 64,063 SCF/hr Refinery Gas (3.5% sulfur) 308 gal/hr Fuel Oil (1.4% sulfur)
Stack Flow Rate: 2,540,899 SCF/hr

$\underline{SO_2}$ AP-42 Factor: 160 x S lbs SO_2/1000 gal oil

$$\begin{array}{lrll} \text{Expected:} & 64.063 \frac{\text{1000 SCF}}{\text{hr}} & \times 3.5\% \times 1.069^* & = 239.7 \text{ lbs/hr} \\ & .308 \frac{\text{1000 gal}}{\text{hr}} & \times 1.4\% \times 160 & = \underline{68.9} \\ & & & 308.6 \text{ lbs/hr} \end{array}$$

Found: 1.26×10^{-4} lb/SCF x 2,540,899 SCF/hr = 320.2 lbs/hr

* Special Emission Factor, 1.069 x S lbs SO_2/1000 CF refinery gas

AMOCO OIL REFINERY
Catalytic Cracker Regenerator
SCC: 30600201

Feed Rate: 34,485 barrel/day fresh feed
Stack Flow Rate: 5,160,271
Precipitator Efficiency: 94%

$\underline{SO_2}$ AP-42 Factor: 493 lbs $SO_2/10^3$ bbl feed

Expected: $34.485\ 10^3$ bbl/day x 493 x $\frac{1}{24}$ = 708 lbs/hr

Found: 6.853×10^{-5} lb/SCF x 5,160,271 SCF/hr = 353.6 lbs/hr

Experimental EMFAC: 493 x $\frac{354}{708}$ = 246.3 lbs $SO_2/10^3$ bbl feed

$\underline{NO_X}$ AP-42 Factor: 71 lbs $NO_X/10^3$ bbl feed

Expected: 34.485 x 71 x $\frac{1}{24}$ = 102.0 lbs/hr

Found: 4.26×10^{-5} lb/SCF x 5,160,271 SCF/hr = 219.8 lbs/hr

Experimental EMFAC: 71 x $\frac{220}{102}$ = 153 lbs $NO_X/10^3$ bbl feed

PARTICULATES

AP-42 Factor: 242 lbs part./10^3 bbl feed

Expected: 34.485 x 242 x $\frac{1}{24}$ x (1-.94) = 19.8 lbs/hr

Found: 29.5 lbs/hr

Experimental EMFAC: 242 x $\frac{29.5}{19.8}$ = 360 lbs part./10^3 bbl feed

HYDROCARBONS

AP-42 Factor: 220 lbs HC/10^3 bbl feed

Expected: 34.485 x 220 x $\frac{1}{24}$ = 316.1 lbs/hr

Found: 3 ppm

$3 \times 10^{-6} \times 5{,}160{,}271 \times \frac{16}{359}$ = .69 lbs/hr

Experimental EMFAC: 220 x $\frac{69}{316.1}$ = .48 lbs HC/10^3 bbl feed

CHRYSLER MOTORS
Boiler #1 - Gas Fired
SCC: 10200602

Burn Rate: 75.58×10^3 SCF/hr

NO_X AP-42 Factor: 230 lbs $NO_X/10^6$ CF gas

Expected: $0.07558\ 10^6$ CF/hr x 230 = 17.38 lb/hr

Found: 17.8 lb/hr

Experimental EMFAC: $230 \times \frac{17.8}{17.38} = 235.5$ lbs $NO_X/10^6$ CF gas

OWENS-ILLINOIS GLASS COMPANY
"A" Glass Furnace - Gas Fired
SCC: 30501401

Production Rate: 10.2 ton/hr (for SO_2 determination)
9.7 ton/hr (for Particulates)
Burn Rate: 45.5×10^3 SCF/hr & 47.6×10^3 SCF/hr (for NO_X determination)

$\underline{SO_2}$ Found: 17.6 lb/hr & 27.0 lb/hr

Experimental EMFAC:

17.6 lb/hr = 10.2 ton/hr x EMFAC EMFAC = 1.73

27.0 lb/hr = 10.2 ton/hr x EMFAC EMFAC = $\underline{2.66}$

Average = 2.2 lbs SO_2/ton glass

$\underline{NO_X}$ Found: 24.1 lb/hr & 27.3 lb/hr

Experimental EMFAC:

24.1 lb/hr = 0.0455 10^6 SCF/hr x EMFAC EMFAC = 529.7

27.3 lb/hr = 0.0476 10^6 SCF/hr x EMFAC EMFAC = $\underline{573.5}$

Average = 551.6 lbs NO_X/10^6 SCF gas

PARTICULATE

AP-42 Factor: 2.0 lbs part./ton glass

Expected: 9.7 ton/hr x 2.00 = 19.4 lb/hr

Found: 5.6 lbs/hr

Experimental EMFAC: $2.00 \times \frac{5.6}{19.4}$ = 0.58 lbs part./ton glass

$\underline{H_2SO_4}$ Found: 2.86 lb/hr & 1.42 lb/hr

Experimental EMFAC:

2.86 lb/hr = 10.2 ton/hr x EMFAC EMFAC = 0.28

1.42 lb/hr = 10.2 ton/hr x EMFAC EMFAC = $\underline{0.14}$

Average = 0.21 lbs H_2SO_4/ton glass

USS AGRI-CHEM
Nitric Acid Plant
SCC: 30101301

Production Rate: 243 tons/day 100% acid

NO$_X$ AP-42 Factor: 52.5 lbs NO_X/ton acid

Expected: 243 ton/day x 52.5 lbs/ton ÷ 24 = 531.6 lb/hr

Found: 612 lb/hr

Experimental EMFAC: $52.5 \times \frac{612}{531.6} = 60.4$ lbs NO_X/ton acid

ALPHA PORTLAND CEMENT
Main Kiln - Coal Fired
SCC: 30500605

Production Rate: 26.025 ton/hr (for SO_2 determination)
24.0 ton/hr (for NO_x determination)
23.65 ton/hr (for Particulates)
26.025 ton/hr (for H_2SO_4 determination)
Precipitator Efficiency: 99.6%

SO_2 AP-42 Factor: 23.8 lbs SO_2/ton cement

Expected: 26.025 ton/hr x 23.8 lbs/ton = 619.4 lb/hr

Found: 740 lb/hr

$$\text{Experimental EMFAC} = 238 \times \frac{740}{619.4} = 28.4 \text{ lbs } SO_2\text{/ton cement}$$

NO_x AP-42 Factor: 2.6 lbs NO_x/ton cement

Expected: 24.0 ton/hr x 2.6 lbs/ton = 62.4 lb/hr

Found: 190 lb/hr

$$\text{Experimental EMFAC: } 2.6 \times \frac{190}{62.4} = 2.9 \text{ lbs } NO_x\text{/ton cement}$$

PARTICULATES

AP-42 Factor: 228 lbs part./ton cement

Expected: 23.65 x 228 x (1-.996) = 21.6 lb/hr

Found: 19.2 lb/hr

$$\text{Experimental EMFAC} = 228 \times \frac{19.2}{21.6} = 202.7 \text{ lbs part./ton cement}$$

H_2SO_4 Found: 7.6 lb/hr

$$\text{Experimental EMFAC} = \frac{7.6 \text{ lb/hr}}{26.025 \text{ ton/hr}} = 0.29 \text{ lbs } H_2SO_4\text{/ton cement}$$

APPENDIX II

SOURCE TEST REPORTS
(Tests Conducted in 1976)

SOURCE TEST REPORT

ALPHA PORTLAND CEMENT

ST. LOUIS, MISSOURI

#2 KILN

TABLE OF CONTENTS

PAGE

SUMMARY 46

1.0 INTRODUCTION 47

2.0 PROCESS DESCRIPTION 48

3.0 PROCESS OPERATION 49

4.0 SOURCE TEST DESCRIPTION 50

5.0 SAMPLING AND ANALYTICAL PROCEDURES 52

- 5.1 PARTICULATE MATTER 52
- 5.2 NITROGEN OXIDE 54
- 5.3 SULFURIC ACID MIST AND SULFUR DIOXIDE 54
- 5.4 PARTICLE SIZE 56

6.0 RESULTS AND DISCUSSION 58

APPENDIX - CALCULATIONS AND FIELD DATA 68

FIGURES

		PAGE
FIGURE 1	SAMPLING LOCATION FOR #2 KILN	51
FIGURE 2	PARTICULATE SAMPLING TRAIN	53
FIGURE 3	SULFURIC ACID MIST SAMPLING TRAIN	55
FIGURE 4	ANDERSEN STACK SAMPLER	57
FIGURE 5	OXYGEN IN FLUE GAS - RECORDER CHART SO_2 TESTS 1, 2, 3	61
FIGURE 6	OXYGEN IN FLUE GAS - RECORDER CHART SO_2 TESTS 4, 5, 6, 7	62
FIGURE 7	SO_2 FORMATION VS. O_2 PRESENT	64
FIGURE 8	SO_3:SO_2 RELATIONSHIP	64
FIGURE 9	PARTICLE SIZE DISTRIBUTION	67

TABLES

PAGE

TABLE 1 SUMMARY OF RESULTS 59

TABLE 2 SULFUR DIOXIDE TEST RESULTS 60

TABLE 3 COMPARISON OF RESULTS 60

TABLE 4 PARTICLE SIZE DISTRIBUTION 65

TABLE 5 PARTICLE SIZE DISTRIBUTION 66

SUMMARY

In conjunction with the Regional Air Pollution Study (RAPS) project, a limited stack testing program is being conducted. This report details the results obtained on the No. 2 kiln at the Alpha Portland Cement Company in St. Louis, Missouri.

The stack testing included the following pollutants: particulates, NO_X (nitrogen oxides), SO_2 (sulfur dioxide) and H_2SO_4 (sulfuric acid mist). Orsat analysis for CO_2 (carbon dioxide), CO (carbon monoxide), and O_2 (oxygen) were also performed. Results of these tests are included in this report. Although these tests were not conducted to ascertain compliance with St. Louis County standards, it is of interest that the particulate emissions are within the limits.

We acknowledge and appreciate the excellent cooperation we obtained from the management and engineering personnel at Alpha Cement.

1.0 INTRODUCTION

The current stack testing program is being conducted in conjunction with the emission inventory work for the St. Louis RAPS project. The stack testing program is being conducted to improve the emission inventory by developing specific plant emission factors which will be used with process rates to determine emissions over the two year program.

This stack test was conducted at the Alpha Portland Cement Company in St. Louis, Missouri. Testing was performed on the No. 2 kiln on 15, 21 and 22 June 1976. Some unexpected results for SO_2 were obtained which necessitated a re-test. Re-testing was performed on 28 and 29 September 1976.

The No. 2 kiln is a coal-fired, wet process kiln. It is equipped with two electrostatic precipitators. This kiln was sampled for total particulates, particle size, NO_X, SO_2, H_2SO_4, CO_2 and O_2.

2.0 PROCESS DESCRIPTION

The No. 2 kiln was installed in 1957. It is 11 feet in diameter and 380 feet long. The wet process is used in which all the ingredients are slurried together with water and fed to the kiln at about 30 to 40 percent moisture. Pulverized coal is fired into the discharge end of the kiln and the combustion gases pass counter currently through the kiln where the raw materials dry and react to form clinkers which are further processed to form the final cement product.

The kiln is equipped with two Research Cottrell electrostatic precipitators. One was installed in 1957 and the other was recently installed (in 1975). The combined efficiency is rated by the manufacturer at 99.6%. Both the No. 1 and No. 2 kilns discharge into a common stack. They are both operated under induced draft. The stack is of masonry construction and is 270 feet tall and 18 feet inside diameter.

3.0 PROCESS OPERATION

The No. 2 kiln was first tested on 15 June and 21 and 22 June. The testing period was broken up due to problems with the kiln which started on 15 June. A blockage developed within the kiln which ultimately forced the operating personnel to shut down the kiln, causing the delay in testing. During testing on 15 June a fairly constant load was maintained but it was not felt that the operation was typical. Once the blockage problem was corrected the kiln was operated smoothly and with a constant load during testing. During testing on 28 and 29 September the kiln was again operated smoothly and at a slightly higher charge rate.

The actual feed rate of the coal is not recorded and may fluctuate some. The rate is set by the operator who visually keeps track of how the clinkers appear at the discharge end. The amount of coal burned is figured from the daily usage and hours of operation.

During the re-test in September it was observed that, while the coal charging rate is maintained fairly constant, the excess air rate varies considerably. The operator attempts to maintain the excess air rate such that the oxygen content of the exit gases from the kiln is approximately 2 to 3 percent. During testing the oxygen content varied from 1 to 5 percent.

4.0 SOURCE TEST DESCRIPTION

The No. 2 kiln was tested in the duct work after the precipitators and ahead of the draft fan. The sampling location is illustrated in Figure 1.

The duct at this point is 7 feet wide by 7 feet high. This location is about five diameters from the last bend in the duct. In accordance with EPA Standard Method 1, twenty-eight sampling points were chosen, seven at each of the four sampling ports. Alpha Cement already had four sampling ports installed at this point.

As illustrated, the duct was sampled vertically. Since there were no overhead structures for supporting a unistrut which could be used for a guiderail for raising and lowering the sample box with the probe attached, a flexible arrangement was made. A heated, flexible Teflon sample line was used between the heated sample probe and the sample oven. A yardarm type arrangement was made and used with a rope to raise and lower the sample probe. The sample oven was then set on a platform with the flexible Teflon line making the connection.

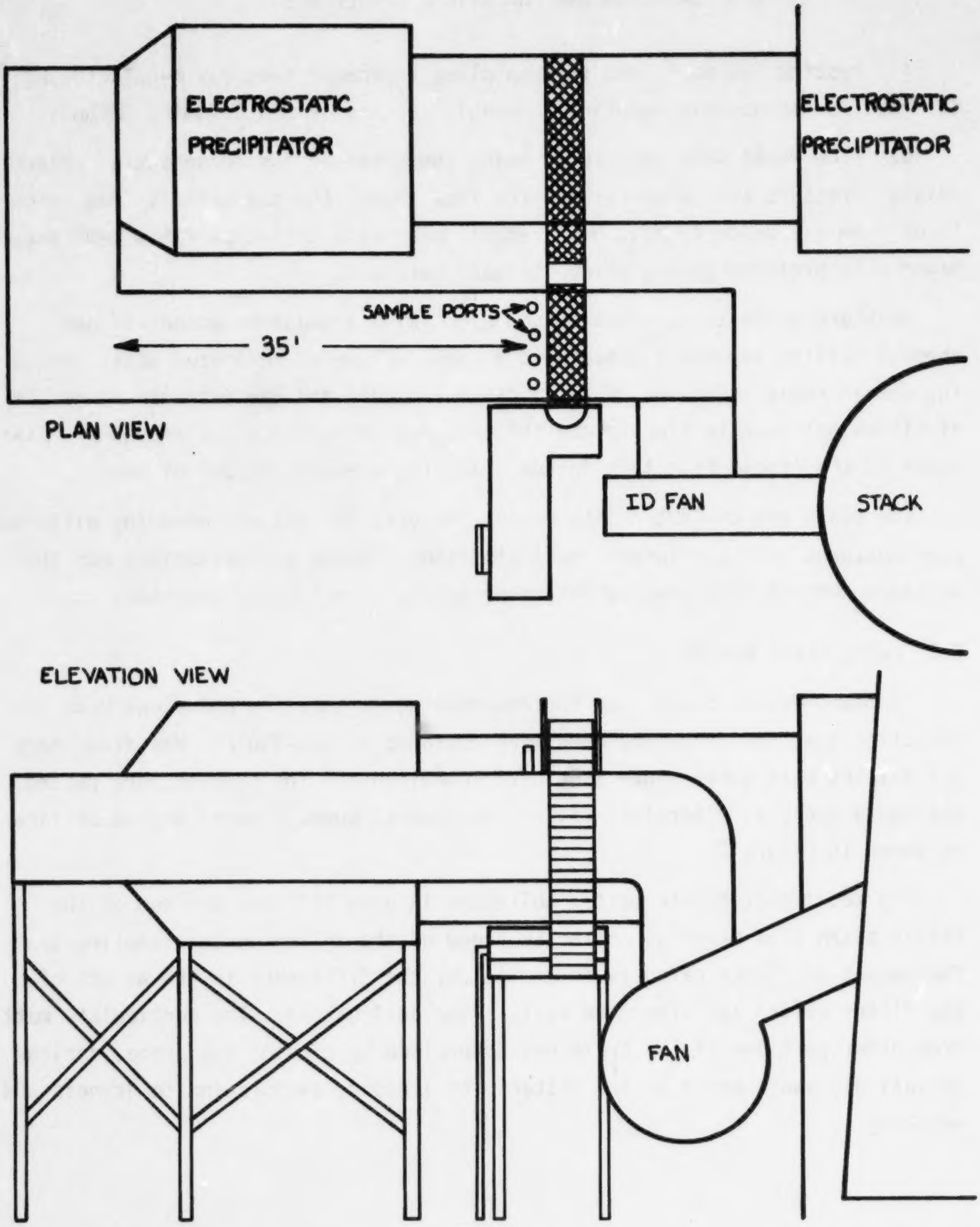

ELECTROSTATIC PRECIPITATOR
ELECTROSTATIC PRECIPITATOR
SAMPLE PORTS
35'
PLAN VIEW
ID FAN
STACK
ELEVATION VIEW
FAN

FIGURE 1 - SAMPLING LOCATION FOR #2 KILN

5.0 SAMPLING AND ANALYTICAL PROCEDURES

All testing was performed with sampling equipment from Joy Manufacturing, designed for isokinetic sampling to enable testing by EPA Standard Methods.

Gas flow rates were calculated using the observed gas temperature, molecular weight, pressure and velocity, and the flow area. The gas velocity was calculated from gas velocity head measurements made with an S-type Pitot tube and a Magnehelic pressure gauge, using Standard Method 2.

Moisture contents were determined by passing a measured amount of gas through chilled impingers containing a known volume of deionized water, measuring the increase in volume of the impingers liquid and the increase in weight of silica gel used to finally dry the gas, and calculating the amount of water vapor in the sample from this increase and the measured amount of gas.

The stack gas concentrations of CO_2, oxygen, CO, and nitrogen (by difference) were measured with a standard Orsat apparatus. These concentrations and the moisture content were used to determine molecular weight of the stack gas.

5.1 PARTICULATE MATTER

Standard Method 5 was used for determining particulate emissions with the exception that the probe and oven were operated at 300-350°F. Measured stack gas samples were taken under isokinetic conditions. The samples were passed through a cyclone, fiberglass filter, impingers, pump, a meter and an orifice as shown in Figure 2.

The total particulate matter collected in each test was the sum of the filter catch plus material collected ahead of the filter in the sampling train. The amount of filter catch is determined by the difference in the weight of the filter before and after the test, after desiccating. The particulate matter from other portions of the train was determined by rinsing the probe, cyclone and all glassware ahead of the filter with acetone, evaporating to dryness and weighing.

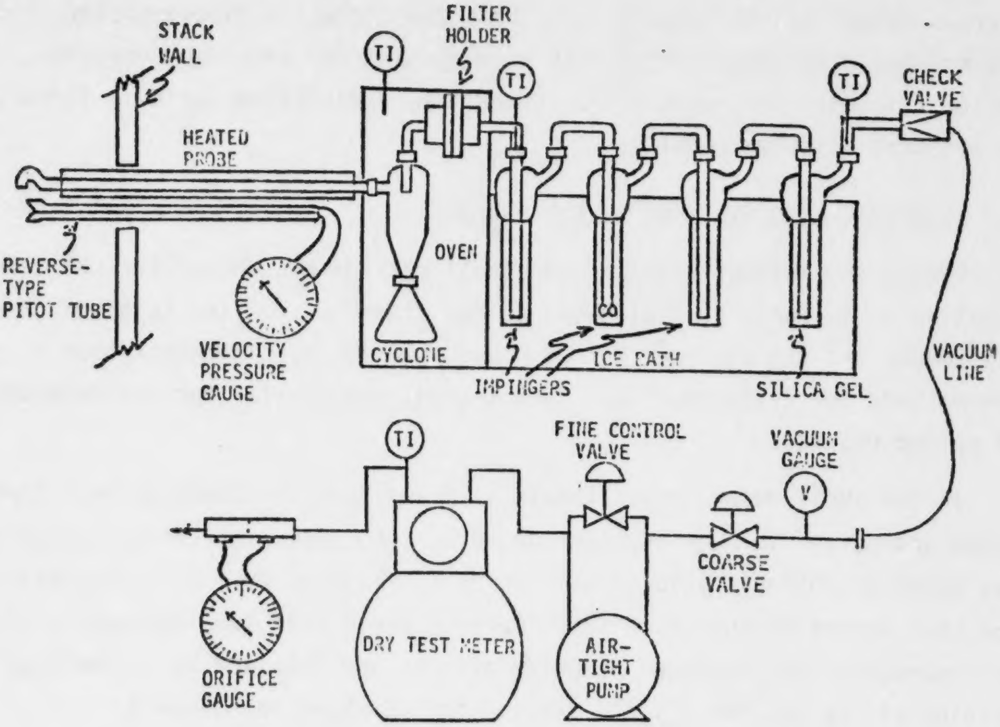

STACK WALL
FILTER HOLDER
TI
TI
TI
CHECK VALVE
HEATED PROBE
OVEN
REVERSE-TYPE PITOT TUBE
VELOCITY PRESSURE GAUGE
CYCLONE
IMPINGERS
ICE BATH
SILICA GEL
VACUUM LINE
TI
FINE CONTROL VALVE
VACUUM GAUGE
V
COARSE VALVE
ORIFICE GAUGE
DRY TEST METER
AIR-TIGHT PUMP

FIGURE 2

PARTICULATE SAMPLING TRAIN

5.2 NITROGEN OXIDE

Using Method 7, gas samples were withdrawn from the stack into evacuated 2-litre flasks containing a dilute solution of hydrogen peroxide and sulfuric acid. The hydrogen peroxide oxidizes the lower oxides of nitrogen (except nitrous oxide) to nitric acid. The resultant solution is evaporated to dryness and treated with phenol disulfonic acid reagent and ammonium hydroxide. The yellow trialkali salt of 6-nitro-1-phenol-2, 4-disulfonic acid is formed, which is measured colorimetrically.

5.3 SULFURIC ACID MIST AND SULFUR DIOXIDE

During the initial testing, the Shell method* was chosen for the determination of sulfuric acid mist and sulfur dioxide. For the tests on 28 and 29 September, the EPA Standard Method 8 was used for this determination to compare the methods for sulfuric acid. Both methods are similar for the determination of sulfur dioxide.

In the Shell method a gas sample is drawn from the stack using a heated probe and passed through a water-cooled coil condenser maintained below the dew point of sulfuric acid at 140° - 194°F, followed by a fritted glass plate and then passed through a chilled impinger train with two impingers containing an isopropanol and hydrogen peroxide mixture and followed by an impinger containing silica gel for drying. This setup is shown in Figure 3.

The condensed sulfuric acid mist in the coil condenser is water washed from the condenser. The final determination is made by titrating the solution with barium chloride, using a thorin indicator. Isopropanol must be added to the solution to be titrated to improve the rapidity with which the barium sulfate precipitates during titration.

---

* Lisle, E.S. and J.D. Sensenbaugh, "The Determination of Sulfur Trioxide and Acid Dew Point in Flue Gases," Combustion, Jan. 1965.

Goksøyr, H. and K. Ross, "The Determination of Sulfur Trioxide in Flue Gases," J. Inst. Fuel, No. 35, 177, (1962).

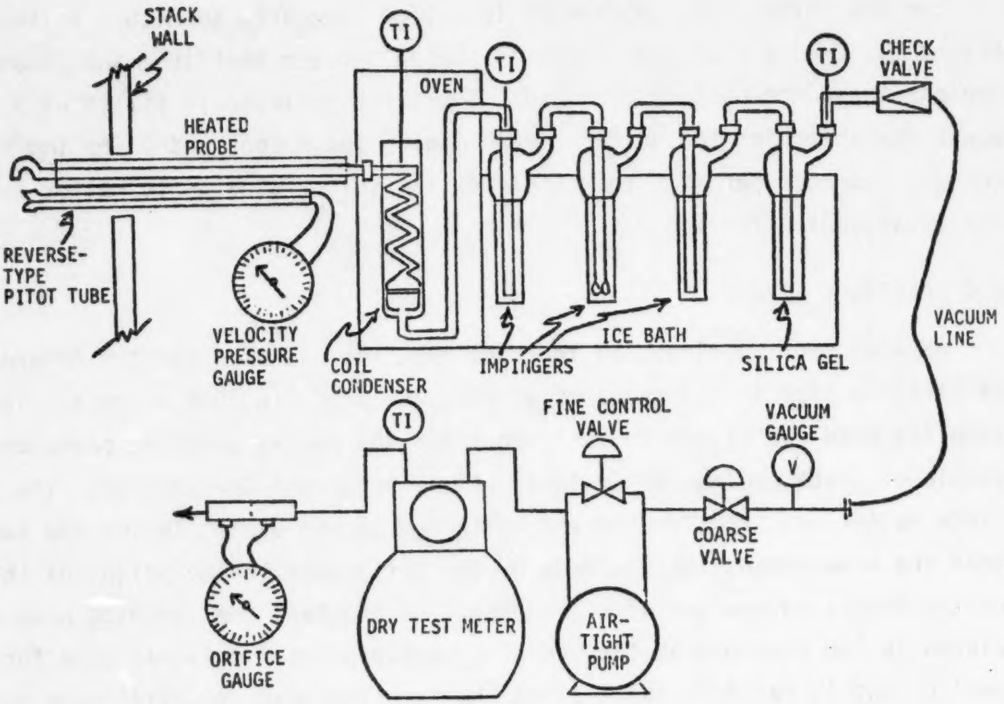

STACK WALL
TI
OVEN
TI
TI
CHECK VALVE
HEATED PROBE
REVERSE-TYPE PITOT TUBE
VELOCITY PRESSURE GAUGE
COIL CONDENSER
IMPINGERS
ICE BATH
SILICA GEL
VACUUM LINE
TI
FINE CONTROL VALVE
VACUUM GAUGE
V
COARSE VALVE
ORIFICE GAUGE
DRY TEST METER
AIR-TIGHT PUMP

FIGURE 3

SULFURIC ACID MIST SAMPLING TRAIN

Sulfur dioxide in the gas sample is oxidized to sulfur trioxide in the impingers containing the hydrogen peroxide. Sulfur dioxide is then determined by titrating the hydrogen peroxide solution with barium chloride, using a thorin indicator.

For EPA Method 8 the equipment is set up similarly to Method 5 (see Figure 2), except that the filter is placed between the first and second impingers and the oven is bypassed. The first impinger is filled with isopropanol for absorbing the sulfuric acid mist. The second and third impingers contain hydrogen peroxide for oxidizing the sulfur dioxide to sulfur trioxide for subsequent titration.

5.4 PARTICLE SIZE

An Andersen fractionating inertial impactor was used for the determination of particle size in the range of approximately 0.7 to 18.0 microns. The sampling head was placed in the oven after the heated sampling probe and a sample of stack gas was drawn isokinetically through the sampler. The particulate matter was fractionated and collected on the plates inside the sample head and a determination was made by the difference in the weight of the filters on the plates before and after testing. On one test the sampling head was placed in the ductwork at the end of a sample probe. This was done for comparison and is far from ideal since the sampling head is upside down during testing and more handling is involved.

Results are expressed for particles of unit density and are corrected for the temperature of the sampling head. The sampling head assembly is shown in Figure 4.

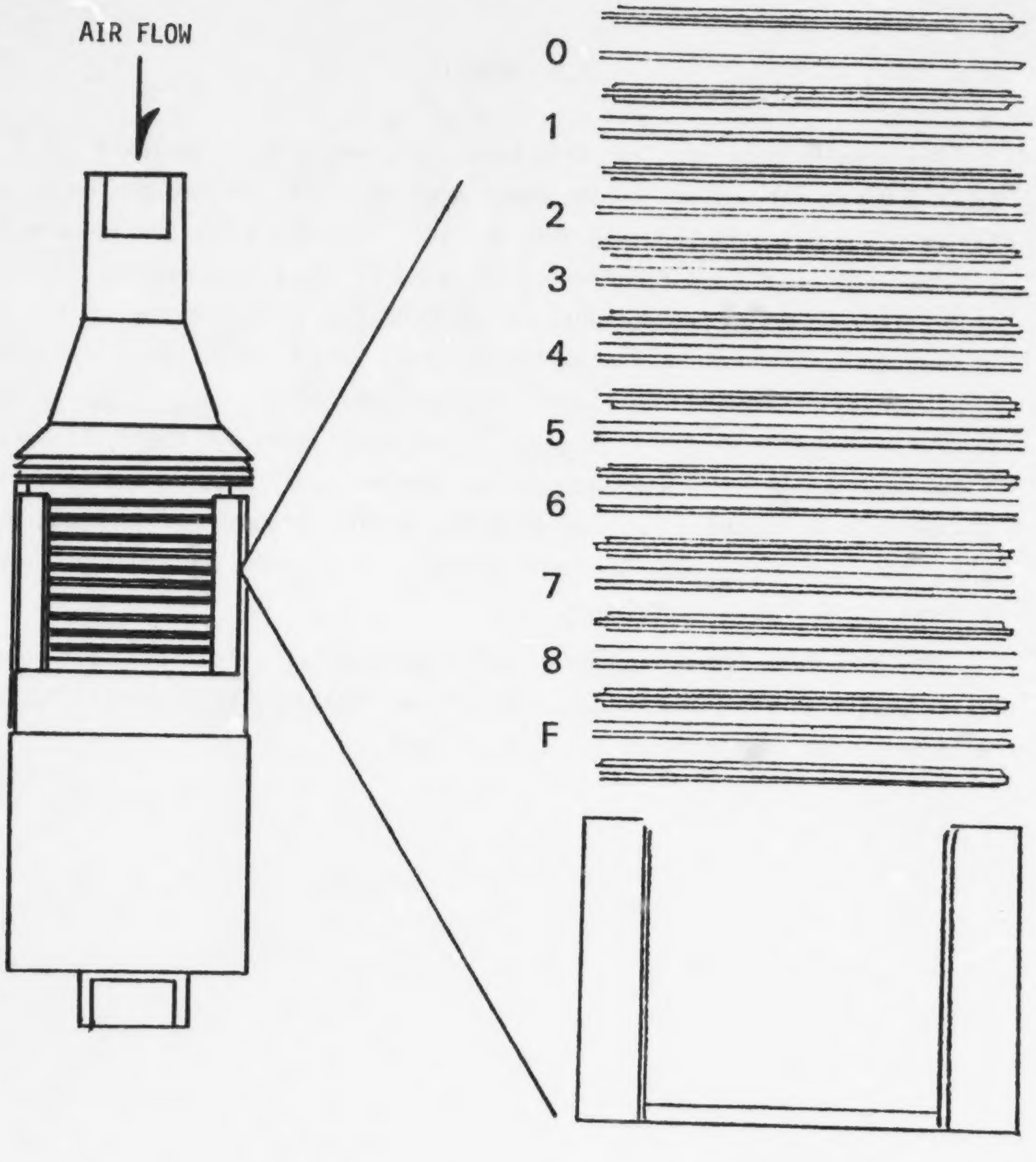

AIR FLOW
0
1
2
3
4
5
6
7
8
F

FIGURE 4
ANDERSEN STACK SAMPLER

6.0 RESULTS

The results obtained from this test are summarized in Tables 1 and 2. Table 2 gives the results of the additional SO_2 tests performed. On 28 and 29 September, a velocity traverse was not made; however, a few points were checked and the velocities were found to be the same as those measured in June. Therefore, the results in Table 2 were calculated using the same stack flow rate as determined on 21 June. A comparison of these results with those predicted by using emission factors from the EPA Publication, AP-42, Compilation of Air Pollutant Emission Factors, is given in Table 3. Although the tests were performed for research purposes and not as part of compliance procedures, standard EPA methods were used. It is of interest to note that the particulate emissions are within the limits for St. Louis County: 19.2 pounds per hour compared with a limit of 40.5 pounds per hour.

The flow rate determined on 21 June was used for calculating all hourly emissions, since there was reason to believe that a leakage problem occurred with the Pitot measurements taken on 15 June.

TABLE 1

SUMMARY OF RESULTS

Date	6/15	6/21	6/22		
Stack Flow Rate - SCFM * dry	63259	56143	56143		
% Water Vapor - % Vol.	29.28	31.24	28.86		
% CO_2 - Vol % dry	14.75	13.27	14.9		
% O_2 - Vol % dry	6.35	8.13	7.5		
% Excess air @ sampling point	43.4	63.8	57.1		
SO_2 Emissions - lbs/hr.		1130			
NO_x Emissions - lbs/hr.	193		190		
H_2SO_4 Mist - lbs/hr.		2.1			
Particulates Probe, Cyclone, & Filter Catch lbs./hr.					
lbs/10^6 Btu					
Total Catch					
lbs./hr.	61.5	22.23	16.1		
lbs/10^6 Btu					
% Isokinetic Sampling	124.7	114.0			

*70° F, 29.92" Hg

TABLE 2

SULFUR DIOXIDE TEST RESULTS

Test Run	1	2	3	4	5	6	7
Date	9/28	9/28	9/28	9/29	9/29	9/29	9/29
SO_2, lbs/hr	310	640	674	1448	1213	290	606
H_2SO_4 mist, lbs/hr	14.5	6.1	6.4	15.5	13.8	7.1	9.1

The large fluctuation in SO_2 emissions in Table 2 appears to be due to similar fluctuations in the excess air in the kiln, as seen in Figures 5 and 6. The amount of SO_2 formed compared with the oxygen present was fairly linear as shown by Figure 7.

TABLE 3

COMPARISON OF RESULTS

POLLUTANT	PREDICTED FROM EMISSION FACTORS	AMOUNT MEASURED
Particulates	20.3 lb/hr	19.2 lb/hr
SO_2, avg. 9/28 & 9/29	620	740 lb/hr
NO_X	62 lb/hr	191 lb/hr

The predicted particulate emissions reflect a precipitator efficiency of 99.6%. The SO_2 tests were re-done since the initial results yielded a comparison of 618 lbs/hr predicted versus 1130 lbs/hr measured. This was unexpected since this indicated that virtually all the SO_2 formed passed on through the system whereas the limestone in the cement mix normally removes approximately 50%. The later tests bore out this assumption.

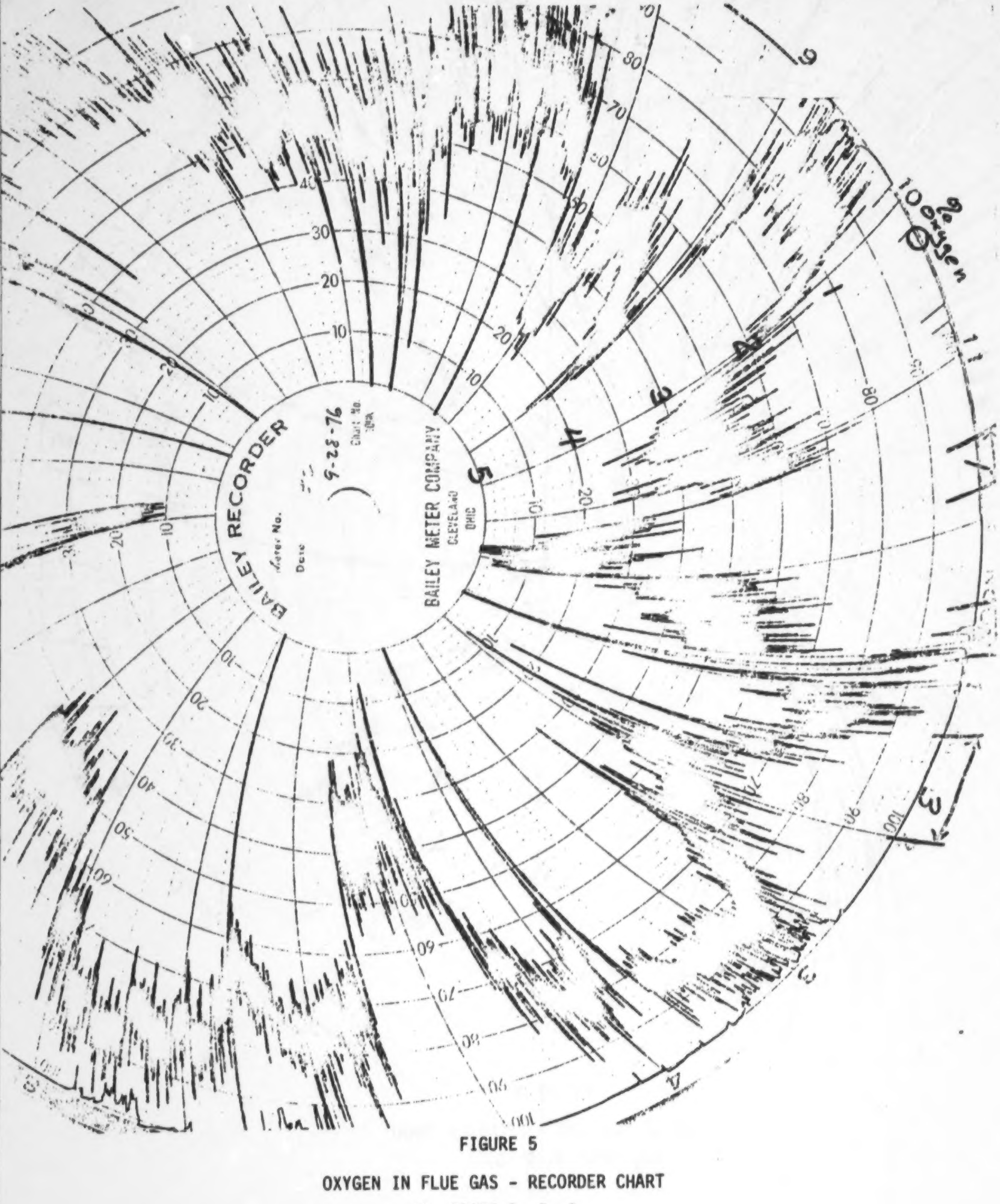


FIGURE 5

OXYGEN IN FLUE GAS - RECORDER CHART

SO_2 TESTS 1, 2, 3

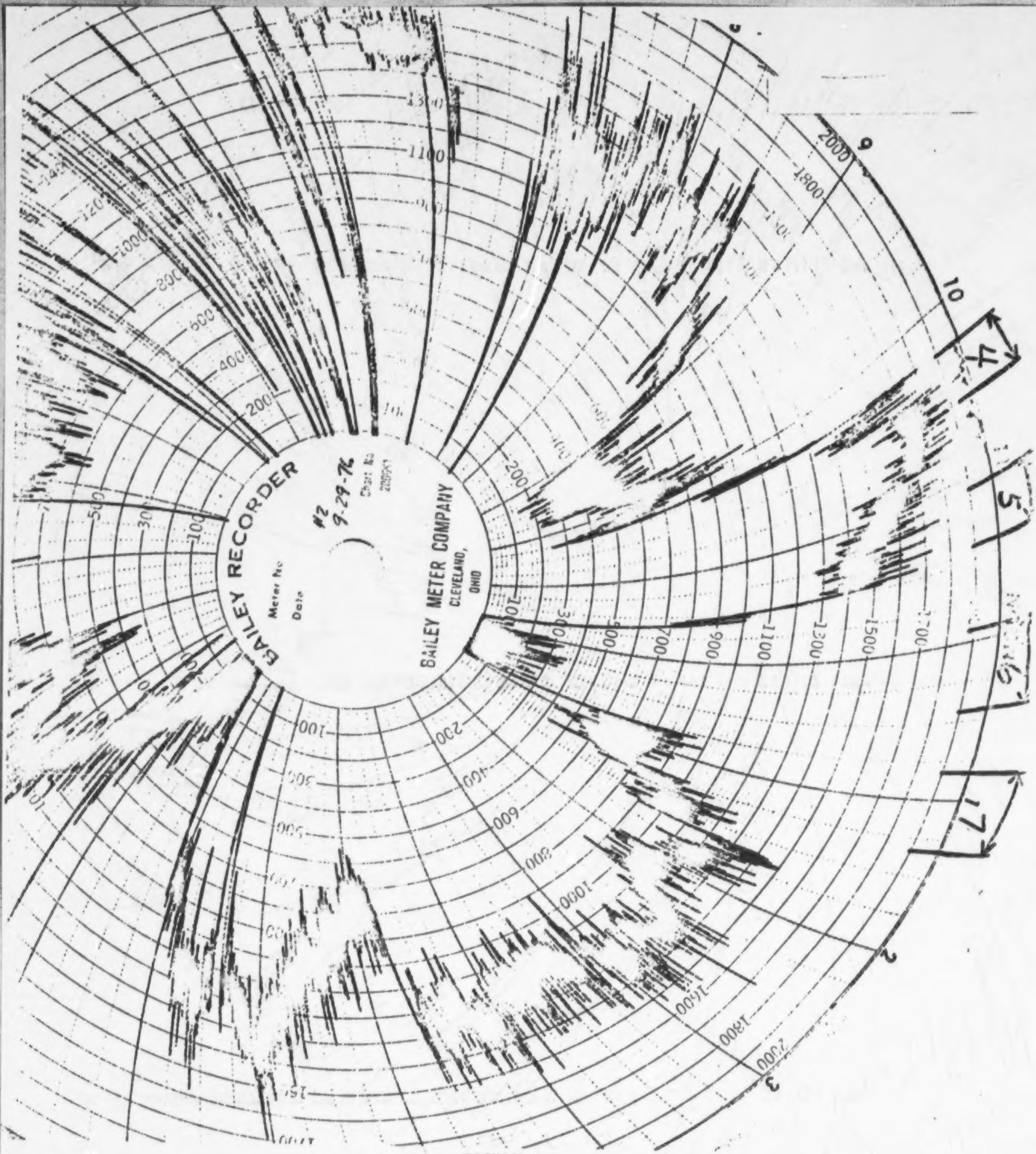


FIGURE 6

OXYGEN IN FLUE GAS - RECORDER CHART

SO_2 TESTS 4, 5, 6, 7

Reproduced from best available copy.

A rough estimate of a sulfur balance around the kiln is given in the Appendix. This balance indicates an emission of 667 lb/hr SO_2 which is a good check on the measured SO_2 results.

Sulfuric acid mist was also measured in the tests on 28 and 29 September. The results of these tests averaged 2.1×10^{-6} lbs/SCF. The percentage of SO_3 to SO_2 was 1.3% and remained fairly constant on all the tests except the first, as shown in Figure 8.

In addition to measuring particulate loadings, a particle size analysis was made with an Andersen impactor. The results are given in Tables 4 and 5 and Figure 9.

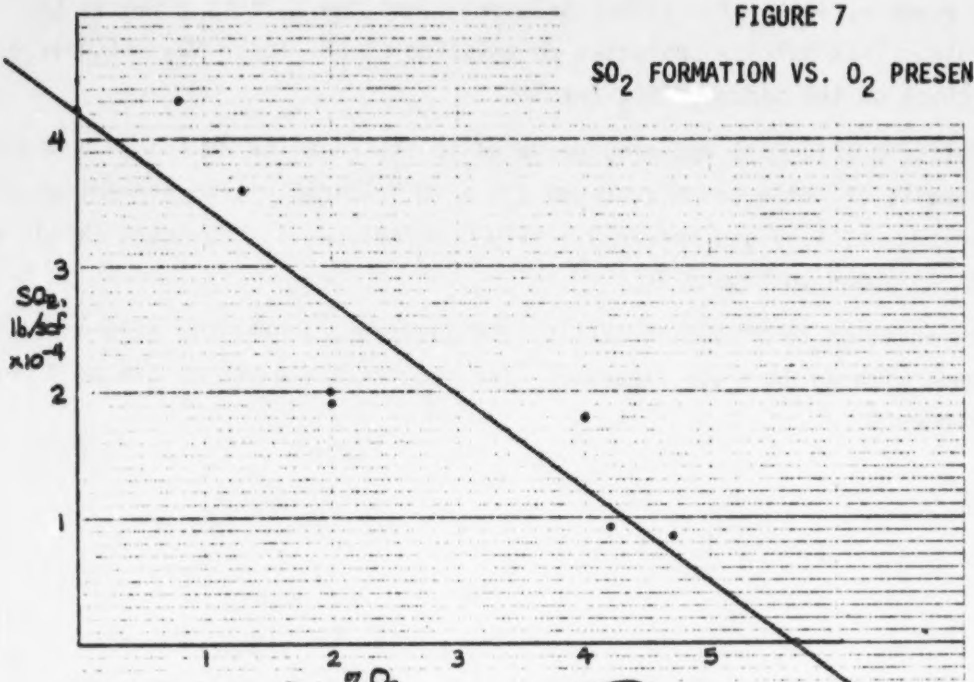


FIGURE 7

SO_2 FORMATION VS. O_2 PRESENT

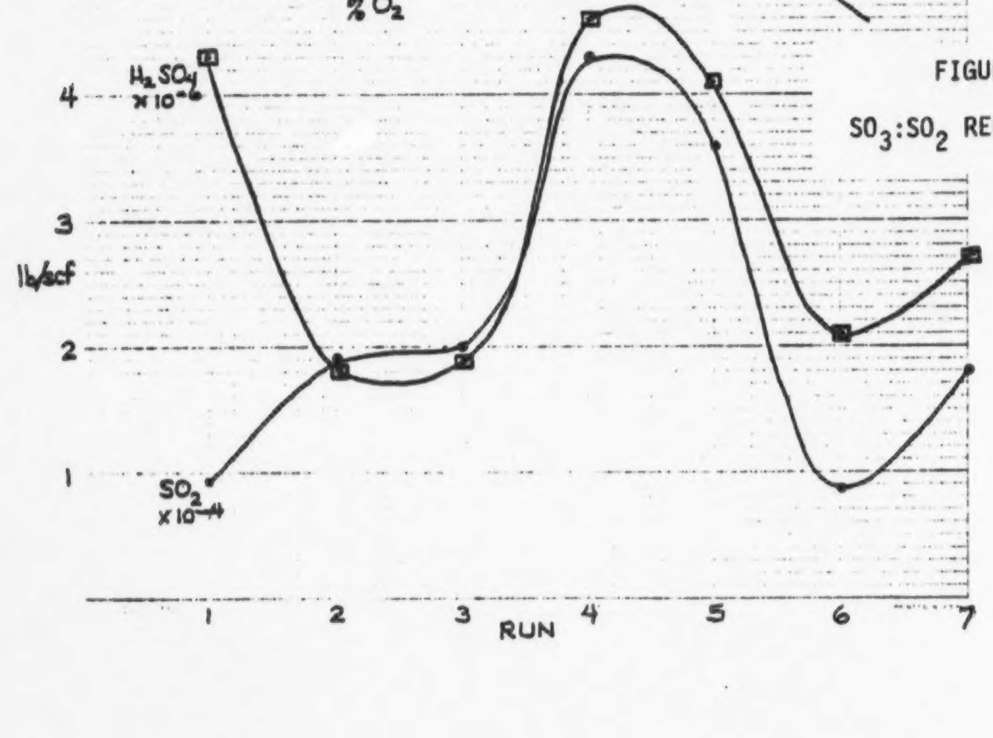


FIGURE 8

$SO_3:SO_2$ RELATIONSHIP

TABLE 4

PARTICLE SIZE DISTRIBUTION

TEST: ALPHA - #1 Date: 6/22
Oven Temp. = 329°F

Plate	Filter Net (mg)	% of Total	ECD (microns)
1	0.5	4.2	17.6
2	0.6	5.0	11.1
3	2.3	19.4	7.3
4	2.3	19.4	5.2
5	2.2	18.5	3.2
6	1.3	10.9	1.7
7	0.5	4.2	1.0
8	0.6	5.0	0.69
Backup	1.6	13.4	<0.69
Total	11.9	100.0	

TEST: ALPHA - #2
Oven Temp. = 355°F Date: 6/22

Plate	Filter Net (mg)	% of Total	ECD (microns)
1	0.3	2.6	17.8
2	0.4	3.4	11.2
3	1.9	16.4	7.4
4	1.9	16.4	5.2
5	1.6	13.8	3.3
6	1.3	11.2	1.7
7	0.5	4.3	1.0
8	0.5	7.8	0.7
Backup	2.8	24.1	<0.7
Total	11.6	100.0	

TABLE 5

PARTICLE SIZE DISTRIBUTION

TEST: ALPHA - #3
Stack Temp. = 450°F

Date: 6/22

Plate	Filter Net (mg)	% of Total	ECD (microns)
1	2.4	9.9	18.0
2	1.8	7.4	11.4
3	2.1	8.7	7.5
4	4.2	17.4	5.3
5	3.6	14.9	5.3
6	3.4	14.0	1.7
7	1.3	5.4	1.1
8	1.6	6.6	0.72
Backup	3.8	15.7	<0.72
Total	24.2	100.0	

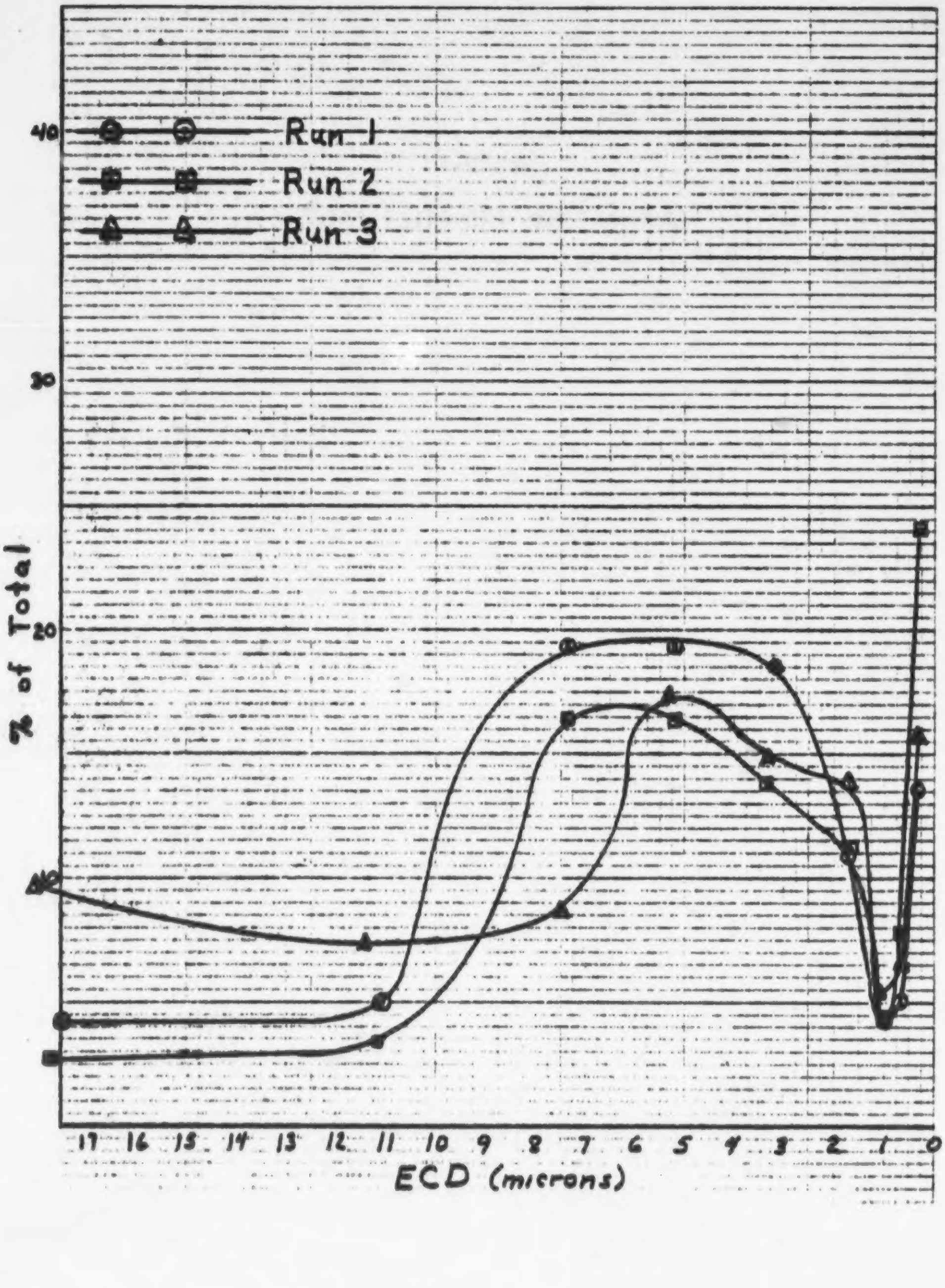


FIGURE 9

PARTICLE SIZE DISTRIBUTION

APPENDIX

CALCULATIONS AND FIELD DATA

PARTICULATE CALCULATIONS

Volume of dry gas sampled at standard conditions - 70° F, 29.92 "Hg

$$V_{mstd} = V_m \, CF_m \left(\frac{Pm}{P_{std}}\right)\left(\frac{Tstd}{Tm}\right) = 0.0334 \, V_m \, CF_m \left(P_B + \frac{\Delta H}{13.6}\right)$$

Vm_{std} = Volume of dry gas sampled at standard conditions, ft^3

Vm = Meter volume sampled, ft^3

CF_m = Meter correction factor

P_m = Meter pressure, barometric pressure, P_B, plus orifice pressure, ΔH, in. Hg.

Pstd = Standard pressure, 29.92 in. Hg.

Tstd = Standard temperature, 530° R or 70° F

Tm = Meter temperature, 530° R for compensated meter

Volume of water vapor at standard conditions

$$Vw = Vl_c \left(\frac{\rho H_2O}{MH_2O}\right)\left(\frac{R \; Tstd}{Pstd}\right) \quad \frac{lb.}{454 \; gm.} \quad = 0.0474 \times Vl_c$$

Vw = Volume of water vapor at standard conditions, ft^3

Vl_c = Volume of liquid collected in impingers and silica gel, ml.

ρH_2O = Density of water, 1g/ml.

M H_2O = Molecular weight of water, 18 lb/lb mol

R = Ideal gas constant, 21.83 in. Hg. - cu. ft./lb-mol - °R

% Moisture in Stack Gas

$$\% \, M = 100 \times \frac{Vw \; std}{Vm_{std} + Vw_{std}}$$

Average molecular weight of dry stack gas

$$MW_D = \left(\%CO_2 \times \frac{44}{100}\right) + \left(\% \, O_2 \times \frac{32}{100}\right) + \left(\% \, N_2 \times \frac{28}{100}\right)$$

Molecular weight of stack gas

$$MW_W = \left(\frac{100 - \% \, M}{100} \times MW_D\right) + \left(\frac{\%M}{100} \times 18\right)$$

Stack velocity at stack conditions

$$V_s = 85.48 \times C_p \left(\frac{Ts \times \Delta P \text{ avg.}}{Ps \times MW_W}\right)^{1/2}$$

V_s = stack velocity, fps.

85.48 = pitot constant, $\frac{\text{ft.}}{\text{sec.}} \left(\frac{\text{lb.}}{\text{lb. Mols - oR}}\right)^{1/2}$

C_p = pitot coefficient, dimensionless

T_s = average stack temperature, ^oR

P_s = stack pressure, barometric pressure plus static pressure, in. Hg.

ΔP Avg = average differential pressure, in. H_2O

Stack gas volume at standard conditions

$$Qs = 3600\left(1 - \frac{\%M}{100}\right) V_s \; A\left(\frac{Tstd}{Ts} \; \frac{Ps}{Pstd}\right)$$

Q_s = stack gas volume flow rate, SCF/hr

A = stack cross sectional area, ft^2

3600 = seconds per hour

$Qs' = Q_s \div 60$ = SCFM

Per cent isokinetic sampling

$$I = \frac{1.667 \left[(0.00267) \quad V_{1c} \quad + \quad \frac{V_{mc}}{T_m} \left(P_B \quad + \frac{\Delta H}{13.6} \right) \right] T_s}{\Theta \; V_s \; P_s \; A_n}$$

I = per cent isokinetic sampling

1.667 = minutes per second, X 100

$0.00267 = \frac{\rho_{H_2O}}{M_{H_2O}} \quad X \quad R \quad X \quad \frac{\text{lb.}}{\text{454 gm.}}$

Θ = sampling time, min.

A_n = cross sectional area of sampling nozzle, ft^2

Particulate emission

$$C_s = 2.205 \quad X \quad 10^{-6} \left(\frac{M_n}{Vm_{std}} \right)$$

C_s = particulate emission, lb/scf

$2.205 \; X \; 10^{-6}$ = pounds per mg.

Mn = total mass of particulate collected, mg.

$C_E = C_S \; X \; Q_s$ = lb/hr

C_E = particulate emission per hour

$C_H = C_E \div H$

C_H = particulate emission, lb. per million BTU

H = heat input, million BTU per hour

Excess air at sample point

$$\% \text{ EA} = \frac{100 \times \% O_2}{(0.266 \times \% N_2) - \% O_2}$$

% EA = excess air at sample point, %

0.266 = ratio of oxygen to nitrogen in air by volume

PARTICULATE SAMPLING CALCULATIONS

Test: Run 1 **Date:** 6/15/76

Material collected (mg)

Filter Catch	=	31.2
Dry Catch		
Acetone Wash	=	275.6
TOTAL	=	306.8

Gas Volume $V_{mstd} = 0.0334 \; V_m \, CF_m \left(P_B + \frac{\Delta H}{13.6} \right)$

$$0.0334 \; (42.24) \; (1.01) \left(29.28 + \frac{0.55}{13.6} \right) = \underline{41.78} \text{ SCF}$$

Volume of water vapor $Vw = 0.0474 \times Vlc$

$0.0474 \; (365 \text{ ml}) = \underline{17.30}$ SCF

% Moisture $\%M = 100 \times \frac{Vwstd}{Vmstd} + Vwstd$

$$100 \times \frac{(1730)}{(41.78) + (17.30)} = \underline{29.28} \%$$

Molecular Weight of dry stack gas

$$MW_D = \%CO2 \times 0.44 + \%O2 \times 0.32 + \%N2 \times 0.28$$

$$(14.75 \times 0.44) + (6.35 \times 0.32) + (78.9 \times 0.28) = \underline{30.61}$$

Molecular Weight of stack gas

$$MWw = \frac{100 - \%M}{100} \times MW_D + \frac{\%M}{100} \times 18$$

$$\left[\frac{100 - 29.28}{100} \times 30.61 \right] + \left[\frac{29.28}{100} \times 18 \right] = \underline{26.92}$$

PARTICULATE SAMPLING CALCULATIONS

Test: Run 1 - Alpha **Date:** 6/15/76

Stack Velocity $Vs = 85.48 \times C_p \left[\frac{Ts \times P\ avg}{P_s \times Mw_w}\right] 1/2$

$$85.48 \times (0.86) \left[\frac{908 \times 0.46}{29.01 \times 26.92}\right] 1/2 = \underline{53.76}\ \text{fps}$$

Stack Gas Volume $Qs = 3600\left(1 - \frac{\%M}{100}\right)(Vs)(A)\left(\frac{Tstd}{Ts}\right)\left(\frac{P_s}{Pstd}\right)$

$$3600 \left[1 - \frac{(29.28)}{100}\right](53.76)\ (49)\ \frac{530}{(908)}\ \frac{(29.01)}{29.92} = \underline{3,795,563}\ \text{SCFH}$$

Stack Emission Rate $C_s = 2.205 \times 10^{-6}\left(\frac{M_n}{V_{Mstd}}\right)$

$$2.205 \times 10^{-6}\ \frac{(306.8)}{(41.78)} = \underline{1.62 \times 10^{-5}}\ \text{lb/scf}$$

$$C_E = C_s \times Qs = (1.62 \times 10^{-5})\ (3,795,563) = \underline{61.5}\ \text{lb/hr}$$

Isokinetic Variations $I = 1.667 \frac{\left[(0.00267)\ V_{1c} + \frac{Vm}{Tm}\left(P_B + \frac{\Delta H}{13.6}\right)\right] Ts}{\theta\ V_s\ P_s\ A_n}$

$$\frac{1.667 \left[(0.00267)\ (365) + \frac{42.66}{530}\left(29.28 + \frac{0.55}{13.6}\right)\right](908)}{(84)\ (53.76)\ (29.01)\ (3.09 \times 10^{-4})} = \underline{124.7\%}$$

Excess Air at Sample Point

$$\%\ EA = \frac{100 \times \%\ O_2}{(0.266 \times \%\ N_2) - \%\ O_2}$$

$$\frac{100\ (6.35)}{(0.266 \times 78.9) - (6.35)} = \underline{43.4}\ \%$$

PARTICULATE SAMPLING CALCULATIONS

Test: Run 2 - Alpha **Date:** 6/21/76

Material collected (mg)

Filter Catch = 14.8
Dry Catch =
Acetone Wash = 86.8

TOTAL = 101.6

Gas Volume $V_{mstd} = 0.0334 \; V_m \; CF_m \left(P_B + \frac{\Delta H}{13.6} \right)$

$0.0334 \; (34.02) \; (1.01) \left(29.53 + \frac{0.33}{13.6} \right) =$ 33.92 SCF

Volume of water vapor $Vw = 0.0474 \times Vlc$

0.0474 (325 ml) = 15.41 SCF

% Moisture $\%M = 100 \times \frac{Vwstd}{Vmstd + Vwstd}$

$100 \times \frac{(15.41)}{(33.92) + (15.41)} =$ 31.24 %

Molecular Weight of dry stack gas

$MW_D = \%CO2 \times 0.44 + \%O2 \times 0.32 + \%N2 \times 0.28$

$(13.27 \times 0.44) + (8.13 \times 0.32) + (78.6 \times 0.28) =$ 30.45

Molecular Weight of stack gas

$MWw = \frac{100 - \%M}{100} \times MW_D + \frac{\%M}{100} \times 18$

$\left[\frac{100 - 31.24}{100} \times 30.45 \right] + \left[\frac{31.24}{100} \times 18 \right] =$ 26.56

PARTICULATE SAMPLING CALCULATIONS

Test: Run 2 - Alpha **Date:** 6/21/76

Stack Velocity $Vs = 85.48 \times C_p \left[\frac{Ts \times P\ avg}{P_s \times Mw_w}\right]^{1/2}$

$$85.48 \times (\ 0.86\ ) \left[\frac{896 \quad \times \quad 0.37}{29.26 \quad \times \quad 26.56}\right]^{1/2} = \underline{\ \ 48.01\ \ }\ \text{fps}$$

Stack Gas Volume $Qs = 3600\left(1 - \frac{\%M}{100}\right)(Vs)(A)\left(\frac{Tstd}{Ts}\right)\left(\frac{P_s}{Pstd}\right)$

$$3600 \left[1 - \frac{(\ 31.24\ )}{100}\right](\ 48.01\ )\quad(\ \ 49\ \ )\quad \frac{530}{(\ 896\ )}\ \frac{(\ 29.26\ )}{29.92} = \underline{\ 3{,}368{,}579\ \ }\ \text{SCFH}$$

Stack Emission Rate $C_s = 2.205 \times 10^{-6}\left(\frac{M_n}{V_{Mstd}}\right)$

$$2.205 \times 10^{-6}\ \frac{(\ 101.6\ )}{(\ 33.92\ )} = \underline{\ \ 6.60 \times 10^{-6}\ \ }\ \text{lb/scf}$$

$$C_E = C_s \times Qs = (6.60 \times 10^{-6})\quad(\ 3{,}368{,}579\ ) = \underline{\ \ 22.23\ \ }\ \text{lb/hr}$$

Isokinetic Variations $I = 1.667 \frac{\left[(0.00267)\ V_{1c} + \frac{Vm}{Tm}\left(P_B + \frac{\Delta H}{13.6}\right)\right]Ts}{\theta\ V_s\ P_s\ A_n}$

$$\frac{1.667\left[(0.00267)\quad(\ \ 325\ \ ) + \frac{34.36}{530}\left(29.53 + \frac{0.33}{13.6}\right)\right](\ \ 896\ \ )}{(\ 84\ )\quad(\ 48.01\ )\quad(29.26)\quad(\ 3.09 \times 10^{-4})} = \underline{114.0\%}$$

Excess Air at Sample Point

$$\%\ EA = \frac{100 \times \%\ O_2}{(0.266 \times \%\ N_2) - \%\ O_2}$$

$$\frac{100\ (\ 8.14\ \ )}{(0.266 \times 78.6) - (8.14\ )} = \underline{63.8\ \%}$$

NO_x EMISSION DATA

Date 6/15/76

Run No.	1	2	3	4				
Time	3:30	3:35	3:40	3:45				
µg NO_2	1720	1880	1500	1440				
T_i- Initial Flask Temp, ^oR	535	535	535	535				
T_f- Final Flask Temp, ^oR	540	540	540	540				
V_{fc}- Flask Volume, ml.	2040	2038	2039	2028				
P_i- Initial Flask Pres, "Hg	2.5	2.5	2.5	2.5				
P_f- Final Flask Pres, "Hg	28.98	28.98	28.98	28.98				
lb/scf NO_2 x 10^{-5}	6.02	6.59	5.26	5.07				
lb/hr NO_2	203	222	177	171				

$$Vsc = \left(17.71 \frac{^oR}{\text{in. Hg}}\right) \quad (Vfc) \quad \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = \text{scf}$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5} \ \frac{\text{lb/scf}}{\mu\text{g/ml}} \left(\frac{\mu\text{g } NO_2}{Vsc}\right) = \text{lb/scf } NO_2$$

NO_x EMISSION DATA

Date 6/22/76

Run No.								
Time	9:35	9:40	9:45	9:50	11:30	11:35	11:40	11:45
µg NO_2	1660	1660	1450	1630	1660	1940	1720	1430
T_i- Initial Flask Temp, °R	530	530	530	530	535	535	535	535
T_f- Final Flask Temp, °R	535	535	535	535	540	540	540	540
V_{fc}- Flask Volume, ml.	2040	2038	2039	2028	2080	2052	2052	2056
P_i- Initial Flask Pres, "Hg	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
P_f- Final Flask Pres, "Hg	29.31	29.31	29.31	29.31	29.31	29.31	29.31	29.31
lb/scf NO_2 x 10^{-5}	5.69	5.70	4.97	5.62	5.63	6.67	5.91	4.91
lb/hr NO_2	192	192	167	189	190	225	199	165

$$Vsc = \left(17.71 \frac{^{o}R}{\text{in. Hg}}\right) (Vfc) \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = \text{scf}$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5} \frac{\text{lb/scf}}{\mu\text{g/ml}} \left(\frac{\mu\text{g } NO_2}{Vsc}\right) = \text{lb/scf } NO_2$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	6/21	6/21		6/21	6/21	6/21
Run No.	1	1		2	2	cond. 2
V_{mc}-Meter Volume, Ft^3	7.48	--		7.37		
Vmstd-Meter Volume, Std. Cond.	7.46			7.35		
P_B-Barometric Pressure, "Hg	29.57			29.57		
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.1			0.1		
V_t-Vol. of Titrant, ml.	7.8	0.0		6.4	0.4	1.3
V_{tb}-Vol. of Titrant for Blank, ml.	--	--				
V_{soln}-Vol. of Solution, ml.	500	100		500	100	100
V_a-Vol. of Aliquot, Titrated, ml.	1.0	20		1.0	20	20
lb/scf H_2SO_4 x 10^{-7}		0.0			2.94	9.55
lb/hr H_2SO_4		0.0			1.0	3.2
lb-scf SO_2 x 10^{-4}	3.69			3.02		
lb/hr SO_2	1243			1017		

$$Vmstd = 0.0334\ (Vm)\ CF \left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{lb\text{-}l}{g\text{-}ml}\right) (V_t - V_{tb})\ (\underline{N}) \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = lb/scf$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{lb\text{-}l}{g\text{-}ml}\right) (V_t - V_{tb})\ (\underline{N}) \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = lb/scf$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	9/28	9/28	9/28	9/28	9/28	9/28
Run No.	1	2	3	1	2	3
V_{mc}-Meter Volume, Ft^3	10.61	10.41	13.97			
Vmstd-Meter Volume, Std. Cond.	10.62	10.42	13.97	10.62	10.42	13.97
P_B-Barometric Pressure, "Hg	29.64	29.64	29.63			
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.5	0.5	0.2			
V_t-Vol. of Titrant, ml.	5.68	5.85	8.1	4.3	1.75	2.55
V_{tb}-Vol. of Titrant for Blank, ml.	--	--	--	--	--	--
V_{soln}-Vol. of Solution, ml.	250	500	500	250	250	250
V_a-Vol. of Aliquot, Titrated, ml.	1.0	1.0	1.0	25	25	25
lb/scf H_2SO_4 $\times 10^{-6}$				4.3	1.8	1.9
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$	0.92	1.9	2.0			
lb/10^6 Btu SO_2						

$$V_{mstd} = 0.0334\,(V_m)\,CF\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{lb\text{-}l}{g\text{-}ml}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{lb\text{-}l}{g\text{-}ml}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	9/29	9/29	9/29	9/29	9/29	9/29
Run No.	4	5	6	4	5	6
V_{mc}-Meter Volume, Ft^3	10.56	10.11	12.05			
Vmstd-Meter Volume, Std. Cond.	10.54	10.09	12.02	10.54	10.09	12.02
P_B-Barometric Pressure, "Hg	29.56	29.55	29.55			
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.5	0.5	0.3			
V_t-Vol. of Titrant, ml.	13.2	10.5	3.0	9.25	7.75	4.8
V_{tb}-Vol. of Titrant for Blank, ml.	--	--	--	--	--	--
Vsoln-Vol. of Solution, ml.	500	500	500	250	250	250
V_a-Vol. of Aliquot, Titrated, ml.	1.0	1.0	1.0	50	50	50
lb/scf H_2SO_4 $\times 10^{-6}$				4.6	4.1	2.1
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$	3.7	3.1	1.3			
lb/10^6 Btu SO_2						

$$\text{Vmstd} = 0.0334\,(\text{Vm})\,\text{CF}\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{\text{lb-l}}{\text{g-ml}}\right)(V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{\text{lb-l}}{\text{g-ml}}\right)(V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	9/29	9/29				
Run No.	7	7				
V_{mc}-Meter Volume, Ft^3	11.82					
Vmstd-Meter Volume, Std. Cond.	11.79	11.79				
P_B-Barometric Pressure, "Hg	29.55					
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.3					
V_t-Vol. of Titrant, ml.	6.1	6.05				
V_{tb}-Vol. of Titrant for Blank, ml.	--	--				
V_{soln}-Vol. of Solution, ml.	500	250				
V_a-Vol. of Aliquot, Titrated, ml.	1.0	50				
lb/scf H_2SO_4 $\times 10^{-6}$		2.7				
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$	1.9					
lb/10^6 Btu SO_2						

$$Vmstd = 0.0334\ (Vm)\ CF\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{lb\text{-}l}{g\text{-}ml}\right)\ (V_t - V_{tb})\ \ (\underline{N})\ \ \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = lb/scf$$

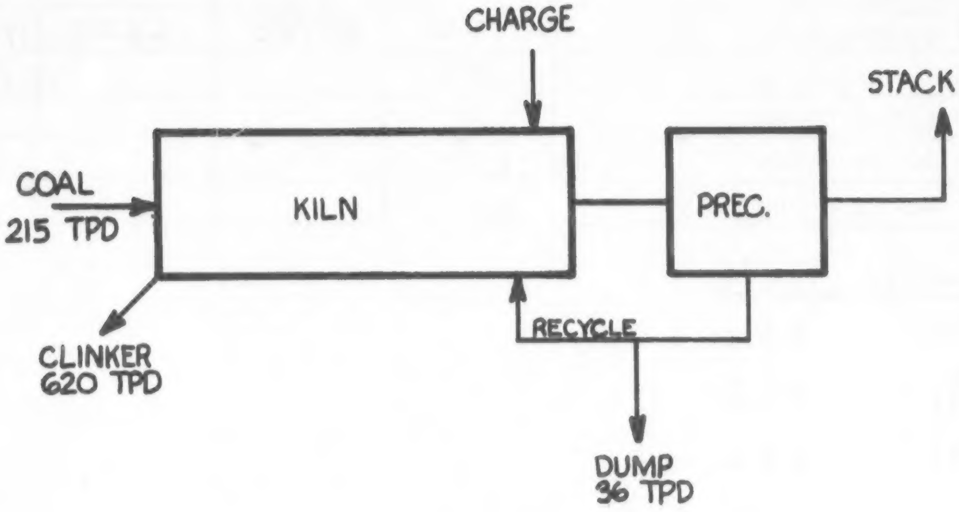
$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{lb\text{-}l}{g\text{-}ml}\right)\ (V_t - V_{tb})\ \ (\underline{N})\ \ \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = lb/scf$$

SULFUR MATERIAL BALANCE

#2 KILN - ALPHA CEMENT

9/28/76


CHARGE
STACK
COAL
215 TPD
KILN
PREC.
RECYCLE
CLINKER
620 TPD
DUMP
36 TPD

Basis: Zero sulfur in charge
3.9% S in coal
0.5% S in clinker
3.5% in recycle and dump

Sulfur Balance: In - Out (product) = Emissions

215 (.039) - 620 (0.005) -36 (.035) = 4.0 TPD sulfur
= 8.0 TPD SO_2
= 667 lb/hr SO_2

SUPPLEMENTARY PROCESS DATA FOR POWER PLANTS

Date	6/15	6/21	6/22	9/28 9/29
Net Unit Load - MW				
Average Steam Load - 10^3 lb/hr				
Boiler Heat Input				
Fuel Burning Rate - lb/hr	17400	16120	16600	17920/18200
Fuel Heating Value - BTU/lb	11815			13,250
Fuel Sulfur Content - %	3.90			3.9
Fuel Ash Content - %	12.72			12.5
Fuel Moisture Content %	9.1			9.2

Process Rate

6/15	25.1	tons/hr
6/21	23.3	"
6/22	24.0	"
9/28	25.8	tons/hr
9/29	26.25	"

ORSAT FIELD DATA

Location Alpha Portland

Comments:

Date 6/15, 6/21, 6/22

Time

Operator Isam

Test	(CO_2) Reading 1	(O_2) Reading 2	(CO) Reading 3
6/15 3:00 PM	14.0	6.0	0
4:00 PM	15.5	6.7	0
6/21 3:00 PM	11.4	10.0	0
3:30 PM	13.0	5.4	0
4:00 PM	15.4	9.0	0
6/22 10:00 AM	13.8	6.4	0
10:30 AM	16.0	8.6	0

ORSAT FIELD DATA

Location Alpha Portland

Comments:

Date 9/28, 9/29

Time

Operator Isam

Test	(CO_2) Reading 1	(O_2) Reading 2	(CO) Reading 3
9/28 12:00	11.8	13.4	0.4
12:45	17.8	7.0	0.4
9/29 10:00	17.2	8.2	0.6
10:25	18.4	6.2	0
10:55	17.6	5.0	1.6

Plant Alpha Portland
Run No. 1
Location #2 Kiln
Date 6/15/76
Operator Griscom, Isam
Meter ΔH@ 1.022
C Factor ____

PARTICULATE FIELD DATA
VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

Ambient Temp °F 90
Bar. Press "Hg 29.28
Assumed Moisture % 10
Probe Tip Dia., In. 1/4
Probe Length 10 ft + flex
Avg. ΔP ____ Avg. ΔH ____

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
1:00 1-1	0	2744.350	0.5	0.6	0.6	240		4	340	160	-3.7	490
-2	3	2746.53	0.54	0.65	0.65	240	90	4	320	190		460
-3	6	2748.13	0.55	0.65	0.65	250	100	4	320	200		440
-4	9	2750.82	0.50	0.60	0.60	250	75	4	320	210		410
-5	12	2751.14	0.50	0.60	0.60	255	75	4	320	210		410
-6	15	2753.74	0.38	0.46	0.46	260	75	3	320	215		400
-7	18	2754.18	0.34	0.40	0.40	255	75	3	320	220		400
	21	2755.51										
1:20 2-1	0	2755.51	0.42	0.50	0.50	240	80	3	320	150		500
-2	3	2756.5	0.44	0.54	0.54	240	70	3.5	310	180		480
-3	6	2758.5	0.45	0.54	0.54	245	70	3.5	310	200		470
-4	9	2760.05	0.45	0.54	0.54	250	70	3.5	315	220		460
-5	12	2761.45	0.45	0.54	0.54	250	70	3.5	315	240		440
-6	15	2763.96	0.45	0.54	0.54	265	75	3.5	315	220		420
-7	18	2764.34	0.45	0.54	0.54	250	70	3.5	320	220		420
	21	2766.02										

Run 1

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
3-1	0	2766.45	0.44	0.54	0.54	210	80	4	300	160		450
-2	3	2767.95	0.48	0.56	0.56	240	70	4	285	185		480
-3	6	2769.49	0.48	0.56	0.56	245	70	4	285	210		470
-4	9	2770.92	0.48	0.56	0.56	250	70	4	285	215		460
-5	12	2772.38	0.48	0.56	0.56	250	70	4	290	230		420
-6	15	2774.88	0.48	0.56	0.56	250	70	4	290	260		410
-7	18	2775.43	0.49	0.58	0.58	265	75	4	310	240		410
	21	2776.91										
4-1	0	2776.91	0.38	0.46	0.46	190	80	3.5	265	150		480
-2	3	2778.25	0.44	0.54	0.54	230	70	4	280	185		480
-3	6	2779.81	0.46	0.54	0.54	235	65	4	290	200		480
-4	9	2781.14	0.44	0.54	0.54	240	65	4	290	210		470
-5	12	2782.67	0.46	0.54	0.54	240	70	4	300	220		460
-6	15	2784.08	0.47	0.55	0.55	245	70	4	300	220		440
-7	18	2785.41	0.47	0.55	0.55	250	70	4	310	225		420
	21	2787.02										

COMMENTS:

Plant Alpha Portland
Run No. # 2
Location #2 Kiln
Date 6/21/76
Operator Griscom, Isam
Meter ΔH@ 1.022
C Factor

PARTICULATE FIELD DATA

VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

Ambient Temp °F 80
Bar. Press "Hg 29.53
Assumed Moisture % 29
Probe Tip Dia., In. 1/4
Probe Length 10 ft + flex
Avg. ΔP 0.4 Avg. ΔH

	Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
					Desired	Actual	Inlet	Outlet					
11:20	4-1	0	2787.03	0.28	.25	.25	200	74	4	300	145		460
	-2	3	2788.35	0.28	.25	.25	200	72	4	290	150		460
	-3	6	2789.35	0.28	.25	.25	200	70	4	275	160		460
	-4	9	2790.51	0.28	.25	.25	200	70	4	260	190		470
	-5	12	2791.65	0.28	.25	.25	190	70	4	245	220		430
	-6	15	2792.75	0.28	.25	.25	200	75	4	240	220		400
	-7	18	2794.79	0.28	.25	.25	180	70	4	245	235		400
		21	2794.85										
11:50	3-1	0	2794.85	0.34	.30	.30	185	75	5	250	160		480
	-2	3	2796.21	0.36	.32	.32	190	70	5	260	155		460
	-3	6	2797.21	0.38	.34	.34	210	70	5	290	185		470
	-4	9	2798.35	0.38	.34	.34	200	68	5	280	190		440
	-5	12	2799.62	0.37	.34	.34	230	74	5	295	240		420
	-6	15	2801.91	0.38	.34	.34	240	70	5	300	230		405
	-7	18	2802.08	0.38	.34	.34	260	70	5	310	235		390
		21	2803.30										

Run #2

	Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger ^oF Temp.		Pump Vacuum In. Hg. Gauge	Box Temp ^oF	Probe Temp ^oF	Stack Press. In.H_2O	Stack Temp. ^oF
					Desired	Actual	Inlet	Outlet					
12:15	2-1	0	2803.30	0.38	.34	.34	170	85	5	290	160		460
	-2	3	2804.58	0.42	.39	.39	230	70	5	310	195		450
	-3	6	2805.84	0.42	.39	.39	230	65	5.5	300	210		450
	-4	9	2807.04	0.40	.39	.39	235	64	5.5	310	220		440
	-5	12	2808.32	0.38	.34	.34	235	62	5.5	315	230		480
	-6	15	2809.62	0.38	.39	.39	240	60	5.5	320	230		400
	-7	18	2810.88	0.38	.34	.34	260	70	5.5	340	250		400
		21	2812.16										
12:38	1-1	0	2812.16	0.38	.34	.34	160	80	5.5	295	175		480
	-2	3	2813.51	0.38	.34	.34	245	78	5	310	210		450
	-3	6	2814.68	0.46	.41	.41	250	68	6	315	220		490
	-4	9	2815.89	0.46	.41	.41	250	68	6	335	240		440
	-5	12	2817.18	0.44	.39	.39	250	70	6	340	250		440
	-6	15	2818.44	0.46	.41	.41	250	70	6	325	240		400
	-7	18	2819.78	0.42	.39	.39	270	70	6	325	245		390
		21	2821.05										

COMMENTS:

PARTICULATE CLEANUP SHEET

Date: 6/15
Plant: Alpha Portland
Run Number: 1
Location Of Sample Port: #2 Kiln
Operator:
Barometric Pressure: 29.28
Sample Box No.
Ambient Temperature 90°F

Impinger H2O

Volume After Sampling 545 ml
Impinger Prefilled With 200 ml
Volume Collected 345 ml

Silica Gel

Weight After 520.0 g
Weight Before 500.0 g
Moisture Weight 20 g Moisture Total 365 g

Dry Probe and Cyclone Catch:
Container No.
Extra No. Weight Results g

Probe, Cyclone, Flask
And Front Of Filter
Acetone Wash:
Container No.
Extra No. Weight Results 0.2756 g

Filter Papers and Dry Filter Particulate

Filter No.	Container No.	Filter No.	Container No.
10			

Filter Particulate Weight 0.0312 g

Total Particulate Weight 0.3068 g

% Moisture By Volume

PARTICULATE CLEANUP SHEET

Date: 6/21

Plant: Alpha Portland

Run Number: 2

Location Of Sample Port: #2 Kiln

Operator:

Barometric Pressure: 29.53

Sample Box No.

Ambient Temperature 80

Impinger H2O

Volume After Sampling 510 ml

Impinger Prefilled With 200 ml

Volume Collected 310 ml

Silica Gel

Weight After 521 g

Weight Before 506 g

Moisture Weight 15 g Moisture Total 325 g

Dry Probe and Cyclone Catch:

Container No.

Extra No. Weight Results g

Probe, Cyclone, Flask
And Front Of Filter
Acetone Wash:

Container No.

Extra No. Weight Results 0.0868

Filter Papers and Dry Filter Particulate

Filter No.	Container No.	Filter No.	Container No.
111			

Filter Particulate Weight 0.0148 g

Total Particulate Weight 0.1016 g

% Moisture By Volume

OXIDES OF NITROGEN FIELD DATA

Date 6/15/76

Plant Alpha Portland Cement

Sample Collected By

Field Data

Clock Time	3:30	3:35	3:40	3:45				
Flask number	1	2	3	4				
Volume of flask (ml)*	2040	2038	2039	2028				
Pressure before sampling in. Hg.	2,5	2.5	2.5	2.5				
Pressure after sampling, in. Hg.	28.98	28.98	28.98	28.98				
Flask temperature, °F	75/80							

* Flask + valve - 25 ml. for absorbing solution

OXIDES OF NITROGEN FIELD DATA

Date 6/22/76

Plant Alpha Portland

Sample Collected By

Field Data

Clock Time	9:35	9:40	9:45	9:50	11:30	11:35	11:40	11:45
Flask number	1	2	3	4	5	6	7	8
Volume of flask (ml)*	2040	2038	2039	2028	2080	2052	2052	2056
Pressure before sampling in. Hg.	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Pressure after sampling, in. Hg.	29.31	29.31	29.31	29.31	29.31	29.31	29.31	29.31
Flask temperature, °F	70/75				75/80			

* Flask + valve - 25 ml. for absorbing solution

GAS SAMPLING FIELD DATA

Material Sampled For SO_2 & SO_3

Date 6/21/76

Plant Alpha

Location #2 Kiln

Bar. Pressure 29.57 "Hg

Comments: 5 foot glass probe & flex line

Point 2-4

Glass Wool in Probe

Ambient Temp 80 °F

Run No 2

Power Stat Setting

Filter Used: Yes ____ No ____

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
4:10 0	2828.46	0.4	0.1	assume 450	210	140		
5	2829.8	0.4	0.1	"	250	140	145	73
10	2830.9	0.4	0.1	"	250		150	74
15	2832.2	0.4	0.1	"	260	154	150	75
20	2833.5	0.4	0.1	"	260	160	150	76
25	2834.7	0.4	0.1	"	260	160	150	80
30	2835.91							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO_2 & SO_3

Date 6/21/76

Plant Alpha

Location #2 Kiln

Bar. Pressure 29.57 "Hg

Comments: 5 foot glass probe
& flex line

Point 2-4

Glass wool in probe

Ambient Temp 80 °F

Run No 1

Power Stat Setting ________

Filter Used: Yes ________ No ____

Operator ______________________________

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
3:15 0	2821.09	0.4	0.1	assume 450	230	159		
5	2822.3	0.4	0.1		260		160	75
10	2823.5	0.4	0.1		260	164	160	75
15		0.4	0.1					
20	2826.0	0.4	0.1		260		150	75
25	2827.2	0.4	0.1		260	164	150	75
30	2828.46							

Comments:

Plant Alpha Portland
Run No. Andersen Run 1
Location #2 Kiln
Date 6/22/76
Operator Grissom, Isam
Meter ΔH@
C Factor

PARTICULATE FIELD DATA

VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

In Oven

Ambient Temp °F 75
Bar. Press "Hg 29.61
Assumed Moisture % 29
Probe Tip Dia., In. 1/4
Probe Length 5 ft glass
Avg. ΔP Avg. ΔH

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
10:20 2-4	0	2835.91	0.4	.36	0.36	120	80	5	310	120	-3.7	450
	5	2838.08	0.4	.36	0.36	190	60	6.5	310	220		450
	10	2840.19	0.4	.36	0.36	210	60	6.8	315	235		"
	15	2842.29	0.4	.36	0.36	225	60	7.0	320	230		"
	20	2844.38	0.4	.36	0.36	240	65	7	330	235		"
	25	2846.54	0.4	.36	0.36	250	70	7	335	240		"
	30	2848.52	0.4	.36	0.36	260	70	7	340	240		"
	35	2850.49	0.42	.38	0.36	265	75	7.5	350	240		"
	40	2852.58	0.42	.38	0.36	270	75	8.0	350	250		"
	45	2854.72										

Plant Alpha Portland
Run No. Andersen Run 2
Location #2 Kiln
Date 6/22/76
Operator
Meter ΔH@
C Factor

PARTICULATE FIELD DATA
VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

In Oven

Ambient Temp °F 75
Bar. Press "Hg 29.61
Assumed Moisture % 29
Probe Tip Dia., In. 1/4
Probe Length 5 ft. glass
Avg. ΔP Avg. ΔH

11:30

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
2-4	0	2854.72	0.42	.38	.38	180	90	6.5	340	200		450
	5	2856.86	.42	.38	.38	220	75	6.5	360	225		"
	10	2859.12	.42	.38	.38	220	70	7.0	345	230		"
	15	2861.04	.42	.38	.38	250	80	7.0	345	230		"
	20	2863.12	.42	.38	.38	260	80	7.0	350	230		"
	25	2865.21	.42	.38	.38	270	80	7.0	355	250		"
	30	2867.25	.42	.38	.38	275	85	7.0	365	270		"
	35	2869.29	.42	.38	.38	285	90	7.5	370	280		"
	40	2871.33	.42	.38	.38	290	90	8	370	285		"
	45	2873.39										

Plant Alpha Portland
Run No. Andersen Run 3
Location #2 Kiln
Date 6/22/76
Operator
Meter ΔH@
C Factor

PARTICULATE FIELD DATA

VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

In Stack
Upside - Down

Ambient Temp °F 75
Bar. Press "Hg 29.61
Assumed Moisture % 29
Probe Tip Dia., In. 1/4
Probe Length 8 ft unheated
Avg. ΔP Avg. ΔH

1:45

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
2-4	0	2873.39	assume 0.42	.38	.38	180	95	7.5	315	450		450
	5	2875.51		.38	.38	220	85	8	320	450		"
	10	2877.54		.38	.38	230	85	8	325	450		"
	15	2879.61		.38	.38	245	85	8	335	450		"
	20	2881.68		.38	.38	255	85	8	345	450		"
	25	2883.69		.38	.38	265	85	8	345	450		"
	30	2885.75		.38	.38	265	90	8	345	450		"
	35	2887.79		.38	.38	260	90	8	345	450		"
	40	2889.83		.38	.38	265	90	8	345	450		"
	45	2892.89										

Particle Size Determination

Test: Run 1 - In Oven Date: 6/22/76

Plate	Tare (g)	Final (g)	Net (mg)	Filter Net	Total	% of Total	Cum %	ECD (Microns)
1	0.1511	0.1516		0.5		4.2	4.2	17.6 & above
2	0.1544	0.1550		0.6		5.0	9.2	11.1
3	0.1439	0.1462		2.3		19.4	28.6	7.3
4	0.1526	0.1549		2.3		19.4	48.0	5.2
5	0.1427	0.1449		2.2		18.5	66.5	3.2
6	0.1548	0.1561		1.3		10.9	77.4	1.7
7	0.1451	0.1456		0.5		4.2	81.6	1.0
8	0.1505	0.1511		0.6		5.0	86.6	0.69
Back Up Filter	0.2136	0.2152		1.6		13.4	100.0	<0.69
		Total		11.9		100.0		

Test: Run 2 - In Oven Date: 6/22/76

Plate	Tare (g)	Final (g)	Net (mg)	Filter Net	Total	% of Total	Cum %	ECD (Microns)
1	0.1415	0.1418		0.3		2.6	2.6	17.8 & above
2	0.1483	0.1487		0.4		3.4	6.0	11.2
3	0.1436	0.1455		1.9		16.4	22.4	7.4
4	0.1508	0.1527		1.9		16.4	38.8	5.2
5	0.1477	0.1493		1.6		13.8	52.6	3.3
6	0.1503	0.1516		1.3		11.2	63.8	1.7
7	0.1415	0.1420		0.5		4.3	68.1	1.0
8	0.1478	0.1487		0.9		7.8	75.9	0.7
Back Up Filter	0.2154	0.2182		2.8		24.1	100.0	<0.7
		Total		11.6		100.0		

Particle Size Determination

Test: Run 3 - In Stack Date: 6/22/76

Plate	Tare(g)	Final(g)	Net(mg)	Filter Net	Total	% of Total	Cum %	ECD (Microns)
1	0.1491	0.1515		2.4		9.9	9.9	18.0 & abo
2	0.1403	0.1421		1.8		7.4	17.3	11.4
3	0.1433	0.1454		2.1		8.7	26.0	7.5
4	0.1389	0.1431		4.2		17.4	43.4	5.3
5	0.1428	0.1464		3.6		14.9	58.3	3.3
6	0.1405	0.1439		3.4		14.0	72.3	1.7
7	0.1420	0.1433		1.3		5.4	77.7	1.1
8	0.1395	0.1411		1.6		6.6	84.3	.72
Back Up Filter	0.2147	0.2185		3.8		15.7	100.0	<0.72
		Total		24.2		100.0		

Test: Date:

Plate	Tare(g)	Final(g)	Net(mg)	Filter Net	Total	% of Total	Cum %	ECD (Microns)
1								
2								
3								
4								
5								
6								
7								
8								
Back Up Filter								
		Total						

PARTICULATE CLEANUP SHEET

Date: 6/22
Plant: Alpha Portland
Run Number: Andersens 1, 2, 3
Location Of Sample Port: #2 Kiln
Operator:
Barometric Pressure: 29.61
Sample Box No.
Ambient Temperature 75

Impinger H_2O

Volume After Sampling 662 ml
Impinger Prefilled With 200 ml
Volume Collected 462 ml

Silica Gel

Weight After 531.5 g
Weight Before 506.0 g
Moisture Weight 25.5 g Moisture Total 487.5 g

Dry Probe and Cyclone Catch:

Container No.
Extra No. Weight Results g

Probe, Cyclone, Flask
And Front Of Filter
Acetone Wash:

Container No.
Extra No. Weight Results 0.0757 g

Filter Papers and Dry Filter Particulate

Filter No.	Container No.	Filter No. B.U.	Container No.
3 ···		𝍸 I	
41 :···		𝍸 𝍸	
61 :····		𝍸 IIII	

Filter Particulate Weight 0.0477 g

Total Particulate Weight 0.1234 g

% Moisture By Volume $V_{m_{std}} = 0.0334(56.98)(1.01)\left(29.61 + \frac{0.38}{13.6}\right) = 56.97$

$V_{w_{std}} = 0.0474(487.5) = 23.11$ $\qquad \% M = 100 \times \frac{23.11}{23.11 + 56.97} = 28.86\ \%$

$MW_D = (14.9 \times .44) + (7.5 \times .32) + (77.6 \times .28) = 30.68$

$MW_w = (.7114 \times 30.68) + (.2886 \times 18) = 27.02$

$C_s = 2.205 \times 10^{-6} \times \frac{(123.4)}{56.97} = \underline{4.78 \times 10^{-6}\ \text{lb/scf}}$

$C_E = 4.78 \times 10^{-6} \times 3{,}368{,}579 = \underline{16.1\ \text{lb/hr}}$

GAS SAMPLING FIELD DATA

Material Sampled For SO_2

Date 9/28

Plant ALPHA

Location #2 KILN

Bar. Pressure 29.64 "Hg

Comments : NO HEAT IN PROBE - INSERTED FULL LENGTH IN STACK FOR 10 MIN TO DRY AND PRE HEAT

FLEX LINE HEATED TO 370°F

Ambient Temp 70 °F

Run No 1

Power Stat Setting

Filter Used: Yes No

Operator

	Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
					Stack	Probe	Coil	Impinger	
								In	Out
11:30A	0	3009.49	≈0.43	0.5	490				
	5	3012.5		0.5					
	10	3014.9		0.5					
	15	3017.5		0.5					
	20	3020.10							
		10.61							

Comments: PULLED "CLEAN" AIR THRU IMPINGERS FOR 10 MIN.

GAS SAMPLING FIELD DATA

Material Sampled For SO_2

Date 9/28

Plant ALPHA

Location #2 KILN

Bar. Pressure ______ "Hg

Comments: SAME AS RUN #1

Ambient Temp 70 °F

Run No 2

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______

	Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
					Stack	Probe	Coil	Impinger In	Impinger Out
12:30	0	3026.06	≈0.43	0.5					
	5	3028.7		0.5					
	10	3031.4		0.5					
	15	3033.9		0.5					
	20	3036.47							
		10.41							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO_2

Date 9/28

Plant ALPHA Location #2 KILN

Bar. Pressure 29.63 "Hg Comments :

Ambient Temp 75 °F

Run No 3

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
1:20 0	3042.05	≈ .43	0.2	495				
10								
20	3049.0		0.2					
30	3052.5		0.2					
40	3056.02							
	13.97							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO2

Date 9/29

Plant ALPHA Location #2 KILN

Bar. Pressure 29.56 "Hg Comments: HOT PROBE, HOT FLEX (360° F)

Ambient Temp 70 °F

Run No 4

Power Stat Setting ____

Filter Used: Yes ____ No ____

Operator ____

	Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
					Stack	Probe	Coil	Impinger	
								In	Out
10:16	0	3059.61	≈0.43	0.5	510	250			
	5	3062.2		0.5					
	10	3064.9		0.5					
	15	3067.6		0.5					
	20	3070.17							
		10.56							

Comments: AFTER RUN, PULLED "CLEAN" AIR FOR 10 MIN.

GAS SAMPLING FIELD DATA

Material Sampled For SO_2

Date 9/29

Plant ALPHA Location

Bar. Pressure 29.55 "Hg Comments: SAME AS #4, PROBE 1 ft. HIGHER

Ambient Temp 70 $^{\circ}F$

Run No 5

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures $^{\circ}F$				
				Stack	Probe	Coil	Impinger	
							In	Out
11:05 0	3075.62	0.43	0.5	505				
5	3078.2		0.5					
10	3080.7		0.5					
15	3083.2		0.5					
20	3085.73							
	10.11							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO_2

Date 9/29

Plant ALPHA Location #2 KILN

Bar. Pressure ______ "Hg Comments: SAME AS RUN #5

Ambient Temp 70 °F

Run No 6

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______

	Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F Stack	Probe	Coil	Impinger In	Impinger Out
11:55	0	3090.56		0.3	505				
	5	3092.6		0.3					
	10	3094.6		0.3					
	15	3096.6		0.3					
	20	3098.6		0.3					
	25	3100.6		0.3					
	30	3102.61							
		12.05							

Comments:

SOURCE TEST REPORT
OWENS-ILLINOIS GLASS
ALTON, ILLINOIS
"A" GLASS FURNACE

TABLE OF CONTENTS

PAGE

1.0 SUMMARY 113

2.0 INTRODUCTION 114

3.0 PROCESS DESCRIPTION 115

4.0 PROCESS OPERATION 116

5.0 SOURCE TEST DESCRIPTION 117

6.0 SAMPLING AND ANALYTICAL PROCEDURES 118
- 6.1 PARTICULATE MATTER 118
- 6.2 NITROGEN OXIDE 118
- 6.3 SULFURIC ACID MIST AND SULFUR DIOXIDE 120
- 6.4 PARTICLE SIZE 120

7.0 RESULTS AND DISCUSSION 124

APPENDIX - CALCULATIONS AND FIELD DATA 129

FIGURES

PAGE

FIGURE 1 CROSS SECTION OF GLASS TANK FURNACE SHOWING REGENERATIVE CHAMBERS 115

FIGURE 2 OVERALL VIEW OF TESTING ARRANGEMENT 117

FIGURE 3 OPERATORS PREPARING EQUIPMENT FOR H_2SO_4 MIST TESTING 117

FIGURE 4 PARTICULATE SAMPLING TRAIN 119

FIGURE 5 SULFURIC ACID MIST SAMPLING TRAIN 121

FIGURE 6 ANDERSEN STACK SAMPLER 123

FIGURE 7 PARTICLE SIZE DISTRIBUTION 127

TABLES

PAGE

TABLE 1 SUMMARY OF RESULTS 125

TABLE 2 PARTICLE SIZE DISTRIBUTION 126

1.0 SUMMARY

In conjunction with the RAPS project, a limited stack testing program is being conducted. This report details the results obtained on the "A" Glass Furnace at the Owens-Illinois Glass Plant in Alton, Illinois.

The stack testing included the following pollutants: sulfur dioxide (SO_2), particulates, particle size, nitrogen oxides (NO_X), sulfuric acid mist (H_2SO_4). Orsat analysis for carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O_2) were also performed. Results of these tests are included in this report. Although these tests were not conducted to ascertain compliance with Illinois standards, it is of interest that the particulate emissions are within the state limits.

We acknowledge and appreciate the excellent cooperation we obtained from the management and engineering personnel at Owens-Illinois.

2.0 INTRODUCTION

The current stack testing program is being conducted in conjunction with the emission inventory work for the St. Louis RAPS project. The stack testing program is being conducted to improve the emission inventory by developing specific plant emission factors which will be used with process rates to determine emissions over the two year program.

This stack test was conducted at the Owens-Illinois Glass Plant in Alton, Illinois. Testing was performed on the "A" Glass Furnace on 24, 25, 26 and 27 May 1976.

The "A" Glass Furnace is a gas-fired, regenerative furnace used for the manufacture of bottles. There are no emission controls on the furnace. This furnace was sampled for total particulates, particle size, NO_X, SO_2, H_2SO_4, CO_2 and O_2.

3.0 PROCESS DESCRIPTION

The "A" Glass Furnace was originally built in the 1920's or 1930's. It was completely overhauled and put back in service in 1974. The operating capacity work rate is 23,960 pounds per hour.

This furnace is a typical regenerative furnace as pictured in Figure 1. The raw materials are charged into one end where the melting takes place. Molten glass is drawn off the other end to the bottle forming machine. As shown by the cross-section view in Figure 1, gas and air are blown into the furnace from one side of the furnace and the flue gases exit from the opposite side. The hot flue gases pass through an open brickwork chamber, heating the bricks, and then out through the stack. This flow is reversed once the bricks are heated and then the entering air is pre-heated by passing through the hot chamber. This switching procedure is done to pre-heat the entering air and maintain a hotter flame in the furnace.

There are no emission controls on this unit. The furnace is a natural draft unit. The stack is of brick construction with a masonry liner. It is 125 feet tall and 5 feet inside diameter at the top.

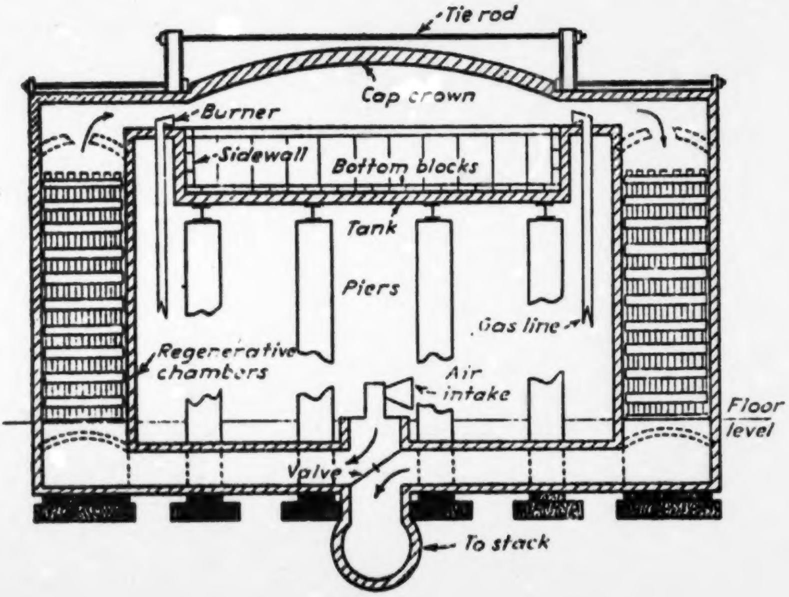


FIGURE 1

CROSS SECTION OF GLASS TANK FURNACE SHOWING REGENERATIVE CHAMBERS

4.0 PROCESS OPERATION

The "A" Glass Furnace was tested on 24-27 May. During the testing period the production rate remained fairly constant. The only fluctuations that occurred during testing were whenever the air flow was reversed in the furnace. The change is very rapid and there was no noticeable change in the stack flow rate. The only change that was noticeable was the change in stack temperature, which changed up to 180°F. This reversal of air occurred about every forty-five minutes.

5.0 SOURCE TEST DESCRIPTION

The "A" Glass Furnace was tested in the stack as shown in Figures 2 and 3. At this point the stack inside diameter is 5 feet and the height above ground level is 40 feet. The flue gases enter the stack just below the ground level. This locates the sampling ports at eight stack diameters from the last obstruction. In accordance with EPA Standard Method 1, twelve sampling points were chosen, six on each of two perpendicular diameters.

At each sampling port a plate was fabricated with a three-inch coupling for attaching the sampling support beam and a vertical arm for fastening a cable to support the cantilevered beam. Owens-Illinois furnished the use of a "cherry-picker" for the entire testing period.

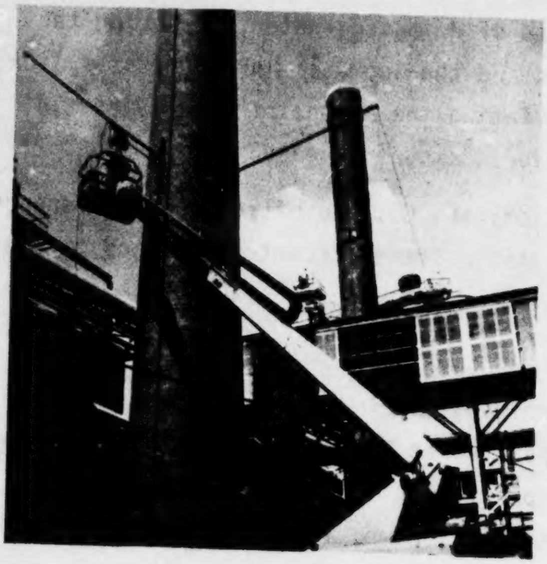


FIGURE 2

OVERALL VIEW OF
TESTING ARRANGEMENT

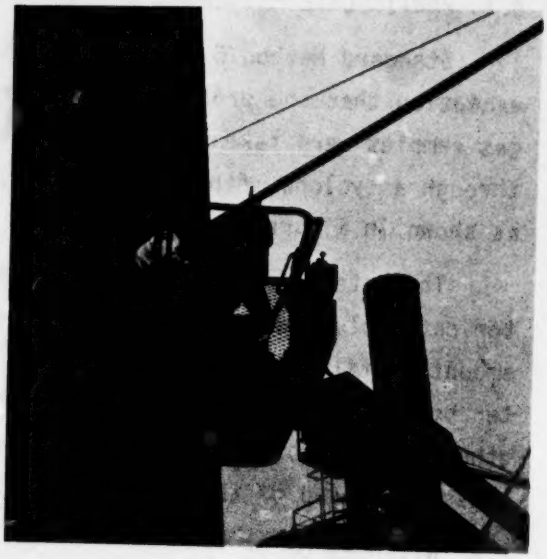


FIGURE 3

OPERATORS PREPARING
EQUIPMENT FOR
H_2SO_4 MIST TESTING

6.0 SAMPLING AND ANALYTICAL PROCEDURES

All testing was performed with sampling equipment from Joy Manufacturing, designed for isokinetic sampling to enable testing by EPA standard methods.

Gas flow rates were calculated using the observed gas temperature, molecular weight, pressure and velocity, and the flow area. The gas velocity was calculated from gas velocity head measurements made with an S-type Pitot tube and a Magnehelic pressure gauge, using Standard Method 2.

Moisture contents were determined by passing a measured amount of gas through chilled impingers containing a known volume of deionized water, measuring the increase in volume of the impingers liquid and the increase in weight of silica gel used to finally dry the gas, and calculating the amount of water vapor in the sample from this increase and the measured amount of gas.

The stack gas concentrations of CO_2, oxygen, CO, and nitrogen by difference were measured with a standard Orsat apparatus. These concentrations and the moisture content were used to determine molecular weight of the stack gas.

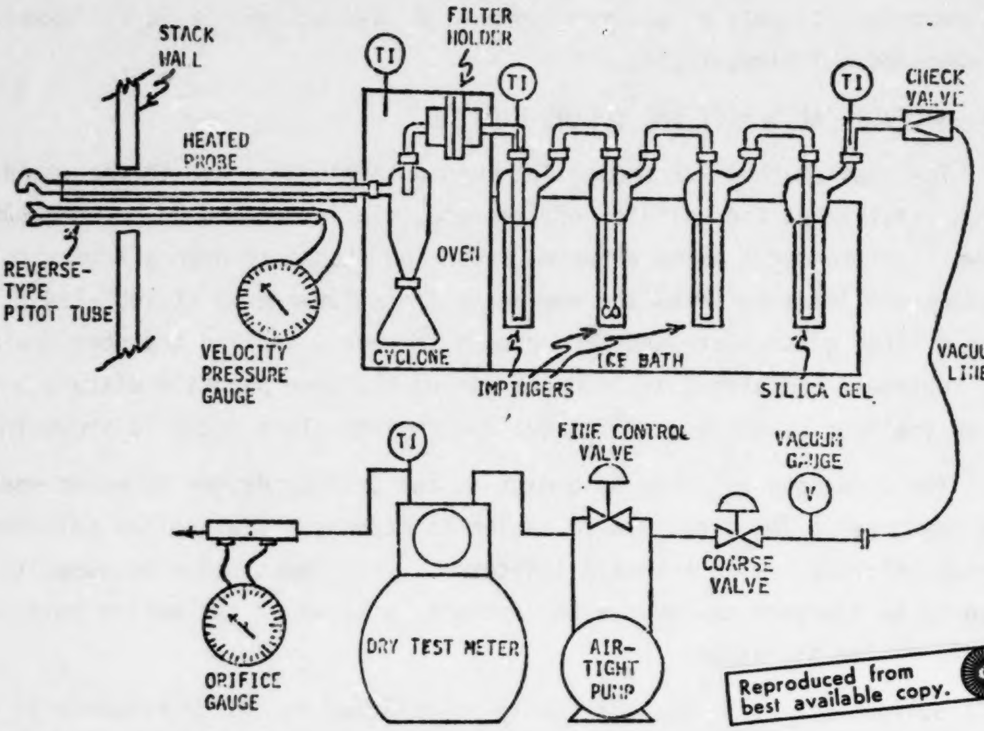
6.1 PARTICULATE MATTER

Standard Method 5 was used for determining particulate emissions with the exception that the probe and oven were operated at 300-350°F. Measured stack gas samples were taken under isokinetic conditions. The samples were passed through a cyclone, fiberglass filter, impingers, pump, a meter and an orifice as shown in Figure 4.

The total particulate matter collected in each test was the sum of the filter catch plus material collected ahead of the filter in the sampling train. The amount of filter catch is determined by the difference in the weight of the filter before and after the test, after desiccating. The particulate matter from other portions of the train was determined by rinsing the probe, cyclone and all glassware ahead of the filter with acetone, evaporating to dryness and weighing.

6.2 NITROGEN OXIDE

Using method 7, gas samples were withdrawn from the stack into evacuated 2-litre flasks containing a dilute solution of hydrogen peroxide and sulfuric


STACK WALL
FILTER HOLDER
TI
TI
TI
CHECK VALVE
HEATED PROBE
OVEN
REVERSE-TYPE PITOT TUBE
VELOCITY PRESSURE GAUGE
CYCLONE
ICE BATH
IMPINGERS
SILICA GEL
VACUUM LINE
TI
FINE CONTROL VALVE
VACUUM GAUGE
V
COARSE VALVE
ORIFICE GAUGE
DRY TEST METER
AIR-TIGHT PUMP

Reproduced from best available copy.

FIGURE 4

PARTICULATE SAMPLING TRAIN

acid. The hydrogen peroxide oxidizes the lower oxides of nitrogen (except nitrous oxide) to nitric acid. The resultant solution is evaporated to dryness and treated with phenol disulfonic acid reagent and ammonium hydroxide. The yellow trialkali salt of 6-nitro-1-phenol-2, 4-disulfonic acid is formed, which is measured colorimetrically.

6.3 SULFURIC ACID MIST AND SULFUR DIOXIDE

The Shell method was chosen for this determination due to uncertainties which exist about the validity of the results using method 8*. A gas sample is drawn from the stack using a heated probe and passed through a water-cooled, coil condenser maintained below the dew point of sulfuric acid at 140°-194°F, followed by a fritted glass plate and then passed through a chilled impinger train with two impingers containing an isopropanol and hydrogen peroxide mixture and followed by an impinger containing silica gel for drying. This setup is shown in Figure 5.

The condensed sulfuric acid mist in the coil condenser is water washed from the condenser. The final determination is made by titrating the solution with barium chloride, using a thorin indicator. Isopropanol must be added to the solution to be titrated to improve the rapidity with which the barium sulfate precipitates during titration.

Sulfur dioxide in the gas sample is oxidized to sulfur trioxide in the impingers containing the hydrogen peroxide. Sulfur dioxide is then determined by titrating the hydrogen peroxide solution with barium chloride, using a thorin indicator.

6.4 PARTICLE SIZE

An Andersen fractionating inertial impactor was used for the determination of particle size in the range of approximately 0.5 to 16 microns. The sampling head was placed in the stack at the end of the sampling probe. The same sampling train

---

*Lisle, E.S. and J.D. Sensenbaugh, "The Determination of Sulfur Trioxide and Acid Dew Point in Flue Gases," Combustion, Jan. 1965.

Goksøyr, H. and K. Ross, "The Determination of Sulfur Trioxide in Flue Gases," J. Inst. Fuel, No. 35, 177, (1962)

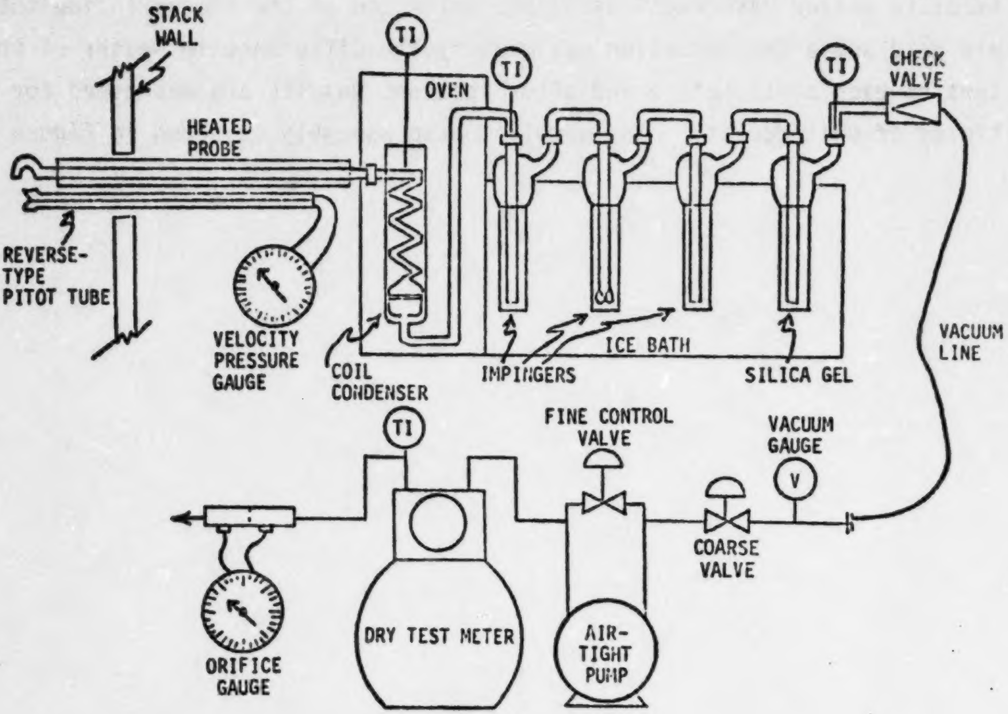

STACK WALL
HEATED PROBE
REVERSE-TYPE PITOT TUBE
VELOCITY PRESSURE GAUGE
TI
OVEN
COIL CONDENSER
TI
TI
CHECK VALVE
IMPINGERS
ICE BATH
SILICA GEL
VACUUM LINE
TI
FINE CONTROL VALVE
VACUUM GAUGE
V
COARSE VALVE
ORIFICE GAUGE
DRY TEST METER
AIR-TIGHT PUMP

FIGURE 5

SULFURIC ACID MIST SAMPLING TRAIN

which was used for total particulates was used for the particle size sampling. A sample of stack gas was drawn isokinetically through the sampler. The particulate matter was fractionated and collected on the plates inside the sample head and a determination was made by the difference in weight of the filters on each plate before and after testing. Results are expressed for particles of unit density. The sampling head assembly is shown in Figure 6.

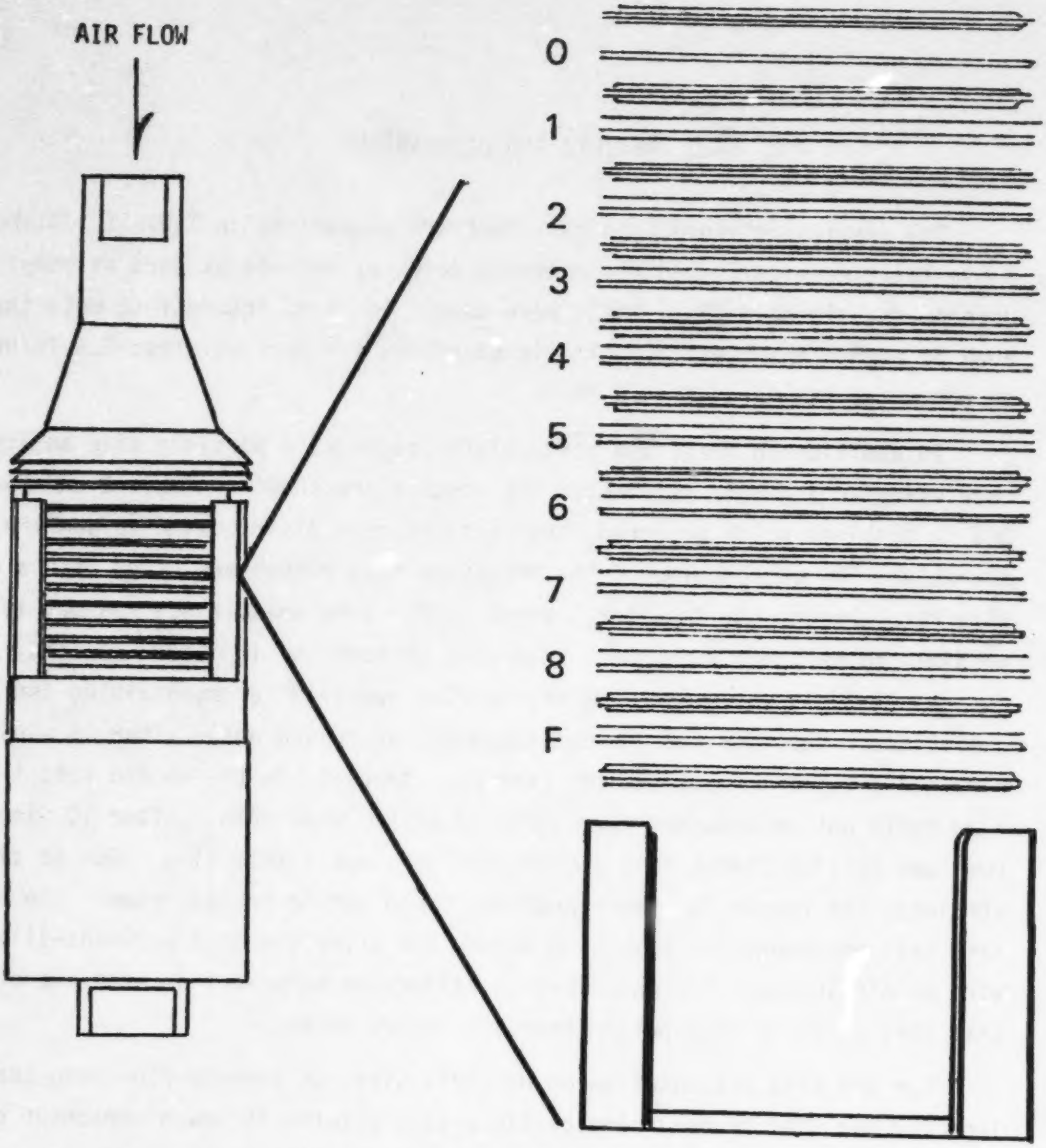

AIR FLOW
0
1
2
3
4
5
6
7
8
F

FIGURE 6
ANDERSEN STACK SAMPLER

7.0 RESULTS AND DISCUSSION

The results obtained from this test are summarized in Table 1. Although these tests were performed for research purposes and not as part of compliance procedures, standard EPA methods were used. It is of interest to note that this oven is within the State of Illinois standards for particulates: 5.6 lb/hr compared to the standard of 19.0 lb/hr.

In addition to measuring particulate loadings, a particle size analysis was made using an Andersen impactor. The results are shown in Table 2 and Figure 7. Due to problems which occurred, the particle size distribution is somewhat questionable. The calibration of the impaction size ranges are based upon a constant flow rate through the impactor. However, for some unexplained reason, it was impossible to maintain a constant flow rate through the impactor. In the first test the sample train was started up at the flow required for maintaining isokinetic conditions. The flow through the equipment decreased until after 15 minutes the flow had dropped in half and the test was stopped. In the second test the proper flow could not be obtained even with the system wide open. After 15 minutes the pump was pulling almost full vacuum and there was little flow. Due to time constraints, the reason for these problems could not be investigated. The exact same test equipment has been used before and after the test at Owens-Illinois with no difficulty. The only obvious difference between this test and others is that this stack is much hotter than any others tested.

For the data presentation on particle size, an average flow rate through the impactor was used to determine particle size cutoffs for each impaction plate. The total particulates collected on the particle size test agreed very well with the total particulates measured with the standard method: 5.3 lb/hr. compared with 5.6 lb/hr.

In addition to the problems with the particle size tests, there was some difficulty experienced with the sulfuric acid mist tests. All three tests were run properly and are valid tests, however, the first two runs were made with a 1/4 inch nozzle and they had to be terminated early due to the vacuum pump pulling wide open after only 20 minutes. On the third test a 1/4 inch nozzle was used to start the test, but when the same conditions persisted, a 1/2 inch nozzle was

TABLE 1

SUMMARY OF RESULTS

Date	5/24	5/25	5/26	5/27	
Stack Flow Rate - SCFM * dry	11543	11479	11607	11543	
% Water Vapor - % Vol.		10.3	11.4		
% CO_2 - Vol % dry		9.8	9.7		
% O_2 - Vol % dry		7.9	8.0		
% Excess air @ sampling point		56.5	57.6		
SO_2 Emissions - lbs/Hr			17.6	27.0	
NO_x Emissions - lbs/Hr	17.6	24.1	27.3		
H_2SO_4 Mist - lbs/Hr.			2.86	1.42	
Particulates Probe, Cyclone, & Filter Catch lbs./hr.		5.5	5.71		
lbs/10^6 Btu					
Total Catch					
lbs./hr.					
lbs/10^6 Btu					
% Isokinetic Sampling		104.5	106.7		

*70° F, 29.92" Hg

Average flow rate used for gaseous emissions

TABLE 2
PARTICLE SIZE DISTRIBUTION

Test: Owens-Illinois #1 Date: 5/27
Stack Temp. = 736°F

PLATE	FILTER NET (mg)	% OF TOTAL	ECD (microns)
1	0.7	2.0	15.4
2	0.7	2.0	9.6
3	0.9	2.6	6.4
4	0.8	2.3	5.0
5	1.1	3.2	2.8
6	8.7	25.3	1.4
7	9.6	27.9	0.88
8	7.6	22.1	0.59
BACKUP FILTER	4.3	12.6	< 0.59
TOTAL	34.4	100.0	

Test: Owens-Illinois #2 Date: 5/27
Stack Temp. = 734°F

PLATE	FILTER NET (mg)	% OF TOTAL	ECD (microns)
1	1.1	3.4	17.0
2	0.6	1.9	10.7
3	0.7	2.2	7.1
4	1.1	3.4	5.0
5	1.5	4.6	3.1
6	4.1	12.7	1.6
7	14.3	44.1	1.0
8	6.0	18.5	0.66
BACKUP FILTER	3.0	9.2	< 0.66
TOTAL	32.4	100.0	

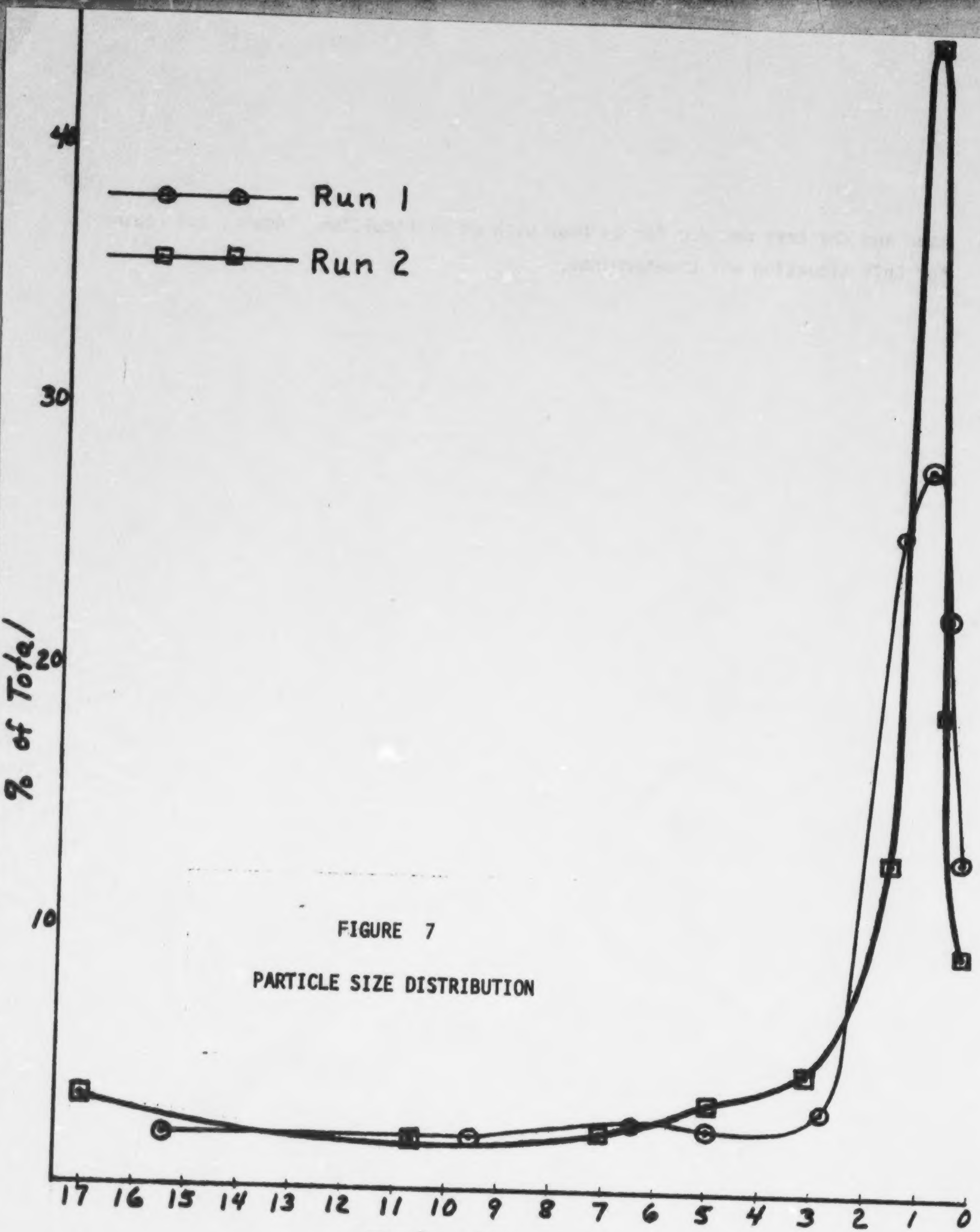


FIGURE 7

PARTICLE SIZE DISTRIBUTION

used and the test was run for an hour with no difficulties. Again, the reason for this situation was undetermined.

APPENDIX

CALCULATIONS AND FIELD DATA

PARTICULATE CALCULATIONS

Volume of dry gas sampled at standard conditions - 70° F, 29.92 "Hg

$$V_{mstd} = V_m \, CF_m \left(\frac{Pm}{P_{std}}\right)\left(\frac{Tstd}{Tm}\right) = 0.0334 \, V_m \, CF_m \left(P_B + \frac{\Delta H}{13.6}\right)$$

Vm_{std} = Volume of dry gas sampled at standard conditions, ft^3

Vm = Meter volume sampled, ft^3

CF_m = Meter correction factor

P_m = Meter pressure, barometric pressure, P_B, plus orifice pressure, ΔH, in. Hg.

Pstd = Standard pressure, 29.92 in. Hg.

Tstd = Standard temperature, 530° R or 70° F

Tm = Meter temperature, 530° R for compensated meter

Volume of water vapor at standard conditions

$$Vw = Vl_c \left(\frac{\rho H_2O}{MH_2O}\right)\left(\frac{R \; Tstd}{Pstd}\right) \quad \frac{lb.}{454 \; gm.} \quad = \quad 0.0474 \times Vl_c$$

Vw = Volume of water vapor at standard conditions, ft^3

Vl_c = Volume of liquid collected in impingers and silica gel, ml.

ρH_2O = Density of water, 1g/ml.

M H_2O = Molecular weight of water, 18 lb/lb mol

R = Ideal gas constant, 21.83 in. Hg. - cu. ft./lb-mol - °R

% Moisture in Stack Gas

$$\% \; M = 100 \times \frac{Vw \; std}{Vm_{std} + Vw_{std}}$$

Average molecular weight of dry stack gas

$$MW_D = \left(\%CO_2 \times \frac{44}{100}\right) + \left(\%\ O_2 \times \frac{32}{100}\right) + \left(\%\ N_2 \times \frac{28}{100}\right)$$

Molecular weight of stack gas

$$MW_W = \left(\frac{100 - \%\ M}{100} \times MW_D\right) + \left(\frac{\%M}{100} \times 18\right)$$

Stack velocity at stack conditions

$$V_s = 85.48 \times C_p \left(\frac{Ts \times \Delta P\ avg.}{Ps \times MW_W}\right)^{1/2}$$

V_s = stack velocity, fps.

85.48 = pitot constant, $\frac{ft.}{sec.} \left(\frac{lb.}{lb.\ Mols - oR}\right)^{1/2}$

C_p = pitot coefficient, dimensionless

T_s = average stack temperature, ^oR

P_s = stack pressure, barometric pressure plus static pressure, in. Hg.

ΔP Avg = average differential pressure, in. H_2O

Stack gas volume at standard conditions

$$Qs = 3600\left(1 - \frac{\%M}{100}\right) V_s\ A\left(\frac{Tstd}{Ts}\ \frac{Ps}{Pstd}\right)$$

Q_s = stack gas volume flow rate, SCF/hr

A = stack cross sectional area, ft^2

3600 = seconds per hour

$Qs' = Q_s \div 60$ = SCFM

Per cent isokinetic sampling

$$I = \frac{1.667 \left[(0.00267) \quad V_{lc} + \frac{V_{mc}}{T_m} \left(P_B + \frac{\Delta H}{13.6} \right) \right] T_s}{\Theta \, V_s \, P_s \, A_n}$$

I = per cent isokinetic sampling

1.667 = minutes per second, X 100

$0.00267 = \frac{\rho_{H_2O}}{M_{H_2O}} \times R \times \frac{\text{lb.}}{454 \text{ gm.}}$

Θ = sampling time, min.

A_n = cross sectional area of sampling nozzle, ft^2

Particulate emission

$$C_s = 2.205 \times 10^{-6} \left(\frac{M_n}{Vm_{std}} \right)$$

C_s = particulate emission, lb/scf

2.205×10^{-6} = pounds per mg.

Mn = total mass of particulate collected, mg.

$C_E = C_S \times Q_s$ = lb/hr

C_E = particulate emission per hour

$C_H = C_E \div H$

C_H = particulate emission, lb. per million BTU

H = heat input, million BTU per hour

Excess air at sample point

$$\% \ EA = \frac{100 \times \% \ O_2}{(0.266 \times \% \ N_2) - \% \ O_2}$$

% EA = excess air at sample point, %

0.266 = ratio of oxygen to nitrogen in air by volume

PARTICULATE SAMPLING CALCULATIONS

Test: Run 1 - A Furnace **Date:** 5/25/76

Material collected (mg)

Filter Catch = 138.1
Dry Catch =
Acetone Wash = 14.7

TOTAL = 152.8

Gas Volume $V_{mstd} = 0.0334\ V_m\ CF_m \left(P_B + \frac{\Delta H}{13.6}\right)$

$$0.0334\ (42.195)\ (1.01\ ) \left(29.57 + \frac{1.04}{13.6}\right) = 42.199 \text{ SCF}$$

Volume of water vapor $V_w = 0.0474 \times V_{lc}$

$0.0474\ (102 \text{ ml}) = 4.835$ SCF

% Moisture $\%M = 100 \times \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$

$$100 \times \frac{(4.835\ )}{(42.199\ ) + (\ 4.835\ )} = 10.3\ \%$$

Molecular Weight of dry stack gas

$$MW_D = \%CO2 \times 0.44 + \%O2 \times 0.32 + \%N2 \times 0.28$$

$$(\ 9.8 \times 0.44) + (\ 7.9 \times 0.32) + (82.3 \times 0.28) = 29.88$$

Molecular Weight of stack gas

$$MW_W = \frac{100 - \%M}{100} \times MW_D + \frac{\%M}{100} \times 18$$

$$\left[\frac{100 - 10.3}{100} \times 29.88\right] + \left[\frac{10.3}{100} \times 18\right] = 28.66$$

PARTICULATE SAMPLING CALCULATIONS

Test: Run 1 - A Furnace **Date:** 5/25/76

Stack Velocity $V_s = 85.48 \times C_p \left[\frac{T_s \times P\ avg}{P_s \times Mw_w}\right]^{1/2}$

$$85.48 \times (0.86)\left[\frac{1151 \times 0.062}{29.52 \times 28.66}\right]^{1/2} = \underline{21.35}\ \text{fps}$$

Stack Gas Volume $Q_s = 3600\left(1 - \frac{\%M}{100}\right)(V_s)(A)\left(\frac{T_{std}}{T_s}\right)\left(\frac{P_s}{P_{std}}\right)$

$$3600\left[1 - \frac{(10.3)}{100}\right](21.35)\ (21.99)\ \frac{530}{(1151)}\ \frac{(29.52)}{29.92} = \underline{688768.6}\ \text{SCFH}$$

Stack Emission Rate $C_s = 2.205 \times 10^{-6}\left(\frac{M_n}{V_{Mstd}}\right)$

$$2.205 \times 10^{-6}\ \frac{(152.8)}{(42.199)} = \underline{7.98 \times 10^{-6}}\ \text{lb/scf}$$

$$C_E = C_s \times Q_s = (7.98 \times 10^{-6})\ (688768.6) = \underline{5.5}\ \text{lb/hr}$$

Isokinetic Variations $I = \dfrac{1.667\left[(0.00267)\ V_{1c} + \frac{V_m}{T_m}\left(P_B + \frac{\Delta H}{13.6}\right)\right]T_s}{\theta\ V_s\ P_s\ A_n}$

$$\frac{1.667\left[(0.00267)\ (102) + \frac{42.617}{530}\left(29.57 + \frac{1.04}{13.6}\right)\right](1151)}{(60)\ (21.35)\ (29.52)\ (1.29 \times 10^{-3})} = \underline{104.5}\ \%$$

Excess Air at Sample Point

$$\%\ EA = \frac{100 \times \%\ O_2}{(0.266 \times \%\ N_2) - \%\ O_2}$$

$$\frac{100\ (7.9)}{(0.266 \times 82.3) - (7.9)} = \underline{56.5}$$

PARTICULATE SAMPLING CALCULATIONS

Test: Run 2 - A Furnace **Date:** 5/26/76

Material collected (mg)

Filter Catch = 144.0
Dry Catch =
Acetone Wash = 18.1

TOTAL = 162.1

Gas Volume $V_{mstd} = 0.0334\ V_m\ CF_m \left(P_B + \frac{\Delta H}{13.6}\right)$

$$0.0334\,(43.56)\,(1.01)\left(29.58 + \frac{1.03}{13.6}\right) = \underline{43.58}\ \text{SCF}$$

Volume of water vapor $Vw = 0.0474 \times Vlc$

$0.0474\,(118\ \text{ml}) = \underline{5.59}$ SCF

% Moisture $\%M = 100 \times \frac{Vwstd}{Vmstd + Vwstd}$

$$100 \times \frac{(5.59)}{(43.58) + (5.59)} = \underline{11.4}\ \%$$

Molecular Weight of dry stack gas

$$MW_D = \%CO2 \times 0.44 + \%O2 \times 0.32 + \%N2 \times 0.28$$

$$(9.7 \times 0.44) + (8.0 \times 0.32) + (82.3 \times 0.28) = \underline{29.87}$$

Molecular Weight of stack gas

$$MWw = \frac{100 - \%M}{100} \times MW_D + \frac{\%M}{100} \times 18$$

$$\left[\frac{100 - 11.4}{100} \times 29.87\right] + \left[\frac{11.4}{100} \times 18\right] = \underline{28.52}$$

PARTICULATE SAMPLING CALCULATIONS

Test: Run 2 - A Furnace

Date: 5/26/76

Stack Velocity $V_s = 85.48 \times C_p \left[\frac{T_s \times P\ avg}{P_s \times Mw_w}\right]^{1/2}$

$$85.48 \times (0.86) \left[\frac{1158 \times 0.065}{29.53 \times 28.52}\right]^{1/2} = \underline{21.98}\ \text{fps}$$

Stack Gas Volume $Q_s = 3600\left(1 - \frac{\%M}{100}\right)(V_s)(A)\left(\frac{T_{std}}{T_s}\right)\left(\frac{P_s}{P_{std}}\right)$

$$3600 \left[1 - \frac{(11.4)}{100}\right](21.98)\ (21.99)\ \frac{530}{(1158)}\ \frac{(29.53)}{29.92} = \underline{696399.2}\ \text{SCFH}$$

Stack Emission Rate $C_s = 2.205 \times 10^{-6}\left(\frac{M_n}{V_{Mstd}}\right)$

$$2.205 \times 10^{-6} \left(\frac{162.1}{43.58}\right) = \underline{8.2 \times 10^{-6}}\ \text{lb/scf}$$

$$C_E = C_s \times Q_s = (8.2 \times 10^{-6})\ (696399.2) = \underline{5.71}\ \text{lb/hr}$$

Isokinetic Variations $I = \frac{1.667\left[(0.00267)\ V_{1c} + \frac{V_m}{T_m}\left(P_B + \frac{\Delta H}{13.6}\right)\right]T_s}{\theta\ V_s\ P_s\ A_n}$

$$\frac{1.667\left[(0.00267)\ (118) + \frac{43.996}{530}\left(29.58 + \frac{1.03}{13.6}\right)\right](1158)}{(60)\ (21.98)\ (29.53)\ (1.29 \times 10^{-3})} = \underline{106.7}\ \%$$

Excess Air at Sample Point

$$\%\ EA = \frac{100 \times \%\ O_2}{(0.266 \times \%\ N_2) - \%\ O_2}$$

$$\frac{100\ (8.0)}{(0.266 \times 82.3) - (8.0)} = \underline{57.6}\ \%$$

NO_x EMISSION DATA

Date 5/24, 5/25

Run No.	1	2	3		1	2	3	4
Time	1400	1405	1410		1430	1432	1434	1436
µg NO_2	950	650	640		750	84	1410	900
T_i- Initial Flask Temp, ^oR	530	530	530		530	530	530	530
T_f- Final Flask Temp, ^oR	535	535	535		535	535	535	535
V_{fc}- Flask Volume, ml.	2040	2038	2039		2040	2038	2039	2028
P_i- Initial Flask Pres, "Hg	2.5	2.5	2.5		2.5	2.5	2.5	2.5
P_f- Final Flask Pres, "Hg	29.55	29.55	29.55		29.52	29.52	29.52	29.52
lb/scf NO_2 $\times 10^{-5}$	3.23	2.21	2.18		2.55	0.29	4.80	3.08
lb/hr NO_2	22.4	15.3	15.1		17.7	2.0	33.2	21.3

$$Vsc = \left(17.71 \frac{^oR}{\text{in. Hg}}\right) (Vfc) \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = \text{scf}$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5} \frac{\text{lb/scf}}{\mu\text{g/ml}} \left(\frac{\mu\text{g } NO_2}{Vsc}\right) = \text{lb/scf } NO_2$$

NO_x EMISSION DATA

Date 5/26

Run No.	1	2	3	4				
Time	1540	1545	1550	1555				
$\mu g\ NO_2$	875	970	1470	1310				
T_i- Initial Flask Temp, ^oR	530	530	530	530				
T_f- Final Flask Temp, ^oR	535	535	535	535				
V_{fc}- Flask Volume, ml.	2040	2038	2039	2028				
P_i- Initial Flask Pres, "Hg	2.5	2.5	2.5	2.5				
P_f- Final Flask Pres, "Hg	29.53	29.53	29.53	29.53				
lb/scf NO_2 $\times 10^{-5}$	2.98	3.30	5.00	4.48				
lb/hr NO_2	20.6	22.9	34.6	31.0				

$$Vsc = \left(17.71 \frac{^oR}{\text{in. Hg}}\right) \quad (Vfc) \quad \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = \text{scf}$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5} \ \frac{\text{lb/scf}}{\mu\text{g/ml}} \left(\frac{\mu g\ NO_2}{Vsc}\right) = \text{lb/scf } NO_2$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	5/26		5/26		5/27	
Run No.	1	1	2	2	3	3
V_{mc}-Meter Volume, Ft^3	5.175		6.04		9.77	
Vmstd-Meter Volume, Std. Cond.	5.17		6.03		9.75	
P_B-Barometric Pressure, "Hg	29.58		29.58		29.58	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.1		0.1		0.1	
V_t-Vol. of Titrant, ml.	1.95	4.2	2.3	4.55	5.5	3.8
V_{tb}-Vol. of Titrant for Blank, ml.	0.1	0.1	0.1	0.1	0.1	0.1
Vsoln-Vol. of Solution, ml.	1000	250	1000	250	1000	250
V_a-Vol. of Aliquot, Titrated, ml.	10	50	10	50	10	50
lb/scf H_2SO_4 $\times 10^{-6}$		4.28		3.99		2.05
lb/hr H_2SO_4		2.96		2.76		1.42
lb-scf SO_2 $\times 10^{-5}$	2.52		2.57		3.90	
lb/hr SO_2	17.45		17.80		27.01	

$$\text{Vmstd} = 0.0334\ (\text{Vm})\ \text{CF}\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$CH_2SO_4 = \frac{\left(1.08 \times 10^{-4}\ \frac{\text{lb-l}}{\text{g-ml}}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = \text{lb/scf}$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{\text{lb-l}}{\text{g-ml}}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = \text{lb/scf}$$

NO_x EMISSION DATA

Date 5/26

Run No.	1	2	3	4				
Time	1540	1545	1550	1555				
$\mu g\ NO_2$	875	970	1470	1310				
T_i- Initial Flask Temp, ^oR	530	530	530	530				
T_f- Final Flask Temp, ^oR	535	535	535	535				
V_{fc}- Flask Volume, ml.	2040	2038	2039	2028				
P_i- Initial Flask Pres, "Hg	2.5	2.5	2.5	2.5				
P_f- Final Flask Pres, "Hg	29.53	29.53	29.53	29.53				
lb/scf NO_2 x 10^{-5}	2.98	3.30	5.00	4.48				
lb/hr NO_2	20.6	22.9	34.6	31.0				

$$V_{sc} = \left(17.71\ \frac{^oR}{\text{in. Hg}}\right) (V_{fc}) \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = \text{scf}$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5}\ \frac{\text{lb/scf}}{\mu\text{g/ml}} \left(\frac{\mu g\ NO_2}{V_{sc}}\right) = \text{lb/scf } NO_2$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	5/26		5/26		5/27	
Run No.	1	1	2	2	3	3
V_{mc}-Meter Volume, Ft^3	5.175		6.04		9.77	
Vmstd-Meter Volume, Std. Cond.	5.17		6.03		9.75	
P_B-Barometric Pressure, "Hg	29.58		29.58		29.58	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.1		0.1		0.1	
V_t-Vol. of Titrant, ml.	1.95	4.2	2.3	4.55	5.5	3.8
V_{tb}-Vol. of Titrant for Blank, ml.	0.1	0.1	0.1	0.1	0.1	0.1
V_{soln}-Vol. of Solution, ml.	1000	250	1000	250	1000	250
V_a-Vol. of Aliquot, Titrated, ml.	10	50	10	50	10	50
lb/scf H_2SO_4 $\times 10^{-6}$		4.28		3.99		2.05
lb/hr H_2SO_4		2.96		2.76		1.42
lb-scf SO_2 $\times 10^{-5}$	2.52		2.57		3.90	
lb/hr SO_2	17.45		17.80		27.01	

$$Vmstd = 0.0334\ (Vm)\ CF \left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{lb\text{-}l}{g\text{-}ml}\right) (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = lb/scf$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{lb\text{-}l}{g\text{-}ml}\right) (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = lb/scf$$

SUPPLEMENTARY PROCESS DATA FOR POWER PLANTS

Date	5/25	5/26	5/27	
Net Unit Load - MW				
Average Steam Load - 10^3 lb/hr				
Boiler Heat Input				
Fuel Burning Rate - MCF/hr	45.5	47.6	47.6	
Fuel Heating Value - BTU/CF	1000	1000	1000	
Fuel Sulfur Content - %				
Fuel Ash Content - %				
Fuel Moisture Content %				

"A" Furnace Feed Rate

5/25	5/26 & 5/27
444,668 lb/day	
18,528 lb/hr	20,325 lb/hr

ORSAT FIELD DATA

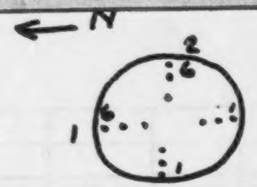
Location Owens Illinois   Comments: A Furnace

Date 5/25   5/26

Time

Operator

Test	(CO_2) Reading 1	(O_2) Reading 2	(CO) Reading 3
5/25 1045	9.6	8.0	-
1110	10.0	7.8	-
5/26 0915	9.6	8.0	-
0935	9.8	8.0	-



Plant Owens Illinois
Run No. 1
Location A Furnace
Date 5/25/76
Operator Griscom / Isam
Meter ΔH@ 1.022
C Factor 0.53

PARTICULATE FIELD DATA
VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

Ambient Temp °F 70
Bar. Press "Hg 29.57
Assumed Moisture % 8
Probe Tip Dia., In. 1/2
Probe Length 10 ft
Avg. ΔP 0.07 Avg. ΔH

	Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
					Desired	Actual	Inlet	Outlet					
10:52	1-1	0	2600.355	0.05	0.85	0.85			7	270	285	-0.65	700
	1-2	5		0.06	1.0	1.0	190	55	8	280	350		705
	1-3	10	2608.5	0.075	1.25	1.25	220	55	9	300	340		660
	1-4	15	2612	0.07	1.2	1.2	240	58	9	320	365		680
	1-5	20	2616	0.06	1.0	1.0	250	57	8	335	355		690
	1-6	25	2619.5	0.05	0.85	0.85	270	59	8	335	325		700
		30	2623.145										
12:03	2-1	0	2623.145	0.05	0.85	0.85			7	285	300		670
	2-2	5	2627.1	0.06	1.0	1.0	230	59	7.5	315	380		690
	2-3	10	2630.6	0.07	1.2	1.2	250	60	9.0	335	360		695
	2-4	15	2634.3	0.08	1.35	1.35	265	60	10.0	350	350		700
	2-5	20		"0.06"	"1.0"								
	2-6	25		"0.055"	"0.9"								
		30											
			2642.55										

11:00 Temp. dropped from 700 to 550 then started back up
Beam fell 1/2 way on point 2-5, probe was still in stack - meter off at appro.
the correct time

Plant Owens Illinois
Run No. 2
Location A Furnace
Date 5/26/76
Operator Griscom / Klein
Meter ΔH@ 1.022
C Factor 0.515

PARTICULATE FIELD DATA
VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

Ambient Temp °F 70
Bar. Press "Hg 29.58
Assumed Moisture % 10
Probe Tip Dia., In. 1/2
Probe Length 10 ft.
Avg. ΔP 0.07 Avg. ΔH

	Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F	
					Desired	Actual	Inlet	Outlet						
9:40	1-1	0	2647.42	0.06	0.95	0.95	170	65	6.5	255	280	-0.65	690	
	1-2	5	2651	0.07	1.1	1.1	205	58	7.5	275	340		705	
	1-3	10	2654.5	0.08	1.3	1.3	230	58	8.5	295	345		710	
	1-4	15	2658.5	0.07	1.1	1.1	245	60		285	320		710	
	1-5	20	2662.0	0.06	0.95	0.95	240	60	6.5	275	310		670	
	1-6	25	2665.5	0.06	0.95	0.95	235	60	6.5	275	320		685	
	off	30	2669.02											
10:55	2-1	0	2669.02	0.05	0.8	0.8	155	70	6	285	280		710	just after starting, temp. dropped to 600 °F
	2-2	5	2672.23	0.06	0.95	0.95	230	75	7	310	350		680	
	2-3	10	2675.65	0.08	1.3	1.3	250	67	9	330	345		700	
	2-4	15	2679.74	0.07	1.1	1.1	265	20	8	350	350		700	
	2-5	20	2683.39	0.06	0.95	0.95	270	70	7	360	350		705	
	2-6	25	2686.78	0.055	0.90	0.90	290	72	7	370	360		710	
	off	30	2690.98											

10:58 stack temp. dropped

PARTICULATE CLEANUP SHEET

Date: 5/25
Plant: Owens Illinois
Run Number: 1
Location Of Sample Port: A Furnace Stack
Operator:
Barometric Pressure: 29.57
Sample Box No.
Ambient Temperature 70 °F

Impinger H2O

Volume After Sampling 296 ml
Impinger Prefilled With 200 ml
Volume Collected 96 ml

Silica Gel

Weight After 512 g
Weight Before 506 g
Moisture Weight 6 g Moisture Total 102 g

Dry Probe and Cyclone Catch:

Container No.
Extra No. Weight Results g

Probe, Cyclone, Flask
And Front Of Filter
Acetone Wash:

Container No.
Extra No. Weight Results 0.0147 g

Filter Papers and Dry Filter Particulate

Filter No.	Container No.	Filter No.	Container No.
7			

Filter Particulate Weight 0.1381 g

Total Particulate Weight 0.1528 g

% Moisture By Volume

PARTICULATE CLEANUP SHEET

Date: 5/26
Plant: Owens Illinois
Run Number: 2
Location Of Sample Port: A Furnace Stack
Operator:
Barometric Pressure: 29.58
Sample Box No.
Ambient Temperature 70°F

Impinger H2O

Volume After Sampling 304 ml
Impinger Prefilled With 200 ml
Volume Collected 104 ml

Silica Gel

Weight After 526 g
Weight Before 512 g
Moisture Weight 14 g Moisture Total 118 g

Dry Probe and Cyclone Catch:
Container No.
Extra No. Weight Results g

Probe, Cyclone, Flask And Front Of Filter Acetone Wash:
Container No.
Extra No. Weight Results 0.0181 g

Filter Papers and Dry Filter Particulate

Filter No.	Container No.	Filter No.	Container No.
8			

Filter Particulate Weight 0.144 g

Total Particulate Weight 0.1621 g

% Moisture By Volume

OXIDES OF NITROGEN FIELD DATA

Date 5/24, 5/25, 5/26

Plant Owens Illinois

Sample Collected By

Field Data

	5/24				5/25			
Clock Time	1400	1405	1410		1430	1432	1434	1436
Flask number	1	2	3		1	2	3	4
Volume of flask (ml)*	2040	2038	2039	~~2028~~	2040	2038	2039	2028
Pressure before sampling in. Hg.	2.5	2.5	2.5		2.5	2.5	2.5	2.5
Pressure after sampling, in. Hg.	29.55	29.55	29.55		29.52	29.52	29.52	29.52
Flask temperature, °F	70/75				70/75			

* Flask + valve - 25 ml. for absorbing solution

OXIDES OF NITROGEN FIELD DATA

Date 5/26/76

Plant Owens Illinois

Sample Collected By

Field Data

5/26

Clock Time	1540	1545	1550	1555				
Flask number	1	2	3	4				
Volume of flask (ml)*	2040	2038	2039	2028				
Pressure before sampling in. Hg.	2.5	2.5	2.5	2.5				
Pressure after sampling, in. Hg.	29.53	29.53	29.53	29.53				
Flask temperature, °F	70/75							

* Flask + valve - 25 ml. for absorbing solution

GAS SAMPLING FIELD DATA

Material Sampled For SO_2 / SO_3

Date 5/26/76

Plant Owens Illinois

Location A furn.

Bar. Pressure 29.58 "Hg

Comments: 1/4 in. sample nozzle
Position : 2-3

Ambient Temp 75 °F

Run No 1

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
1:35 0	2689.985	0.06	0.1	assume 700	270	140	115	75
10	2692.8				350	146	145	70
20	2695.16					150		

Comments: Shut off after 20 min. - pulling full vacuum

GAS SAMPLING FIELD DATA

Material Sampled For SO_2 / SO_3

Date 5/26/76

Plant Owens Illinois Location "A" Furn

Bar. Pressure 29.58 "Hg Comments: 1/4 in. sample nozzle

Ambient Temp 75 °F Position : 2-3

Run No 2

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
3:00 0	2695.21	0.06	0.1	680	295	140		
10	2697.8			705	315	152	155	72
20	2700.1			715	315	154	130	70
25	2701.25							

Comments: Shut off after 25 min. - pulling full vacuum

GAS SAMPLING FIELD DATA

Material Sampled For SO_2 / SO_3

Date 5/27/76

Plant Owens Illinois

Location "A" Furnace

Bar. Pressure 29.58 "Hg

Comments: Started with ¼ in. nozzle
Changed to ½ in. nozzle
after 10 min
Position: 2-3

Ambient Temp 70 °F

Run No 3

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
9:20 0	2702.45	0.08	0.1	735	310	146		
9:30 10 off	2704.90			740	355			
10:15 10 on	2705.87			740	270	156		
20	2708.15			675	375	156		
30	2710.6			710	350	160	145	70
40	2712.95			720	350	164	140	75
50	2715.2			745	350	166	135	73
60	2717.22							

Comments: When stack temp. dropped, the vacuum dropped; as temp. increased again the vacuum increased

Temp. dropped from 740° to 560°

In Stack - Andersen

Plant Owens Illinois
Run No. Andersen - 1
Location A Furnace
Date 5/27
Operator
Meter ΔH@
C Factor

PARTICULATE FIELD DATA
VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

Ambient Temp °F 70
Bar. Press "Hg 29.58
Assumed Moisture % 10
Probe Tip Dia., In. 1/2
Probe Length 8 ft unheated
Avg. ΔP ______ Avg. ΔH ______

11:55

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
2-3	0	2717.22	0.08	1.3	1.3			13.5	165			740
	5	2720.6			1.2	90	65	17	215			720
	10	2724.6			0.85	90	65	18	265			735
	15	2727.58			0.6			21	300			750

Test stopped - flow dropping too much, vacuum too high

Plant Owens Illinois
Run No. Andersen -2
Location A Furnace
Date 5/27/76
Operator
Meter ΔH@
C Factor

PARTICULATE FIELD DATA

VERY IMPORTANT-FILL IN ALL BLANKS

Read and record at the start of each test point.

Ambient Temp OF 70
Bar. Press "Hg 29.58
Assumed Moisture % 10
Probe Tip Dia., In. 1/2
Probe Length 8 ft unheated
Avg. ΔP Avg. ΔH

2:30

Point	Clock	Dry Gas Meter, CF	Pitot in H_2O ΔP	Orifice ΔH in H_2O		Impinger °F Temp.		Pump Vacuum In. Hg. Gauge	Box Temp °F	Probe Temp °F	Stack Press. In. H_2O	Stack Temp. °F
				Desired	Actual	Inlet	Outlet					
2-3	0	2727.59	≈0.08	1.3	1.2			15	125			770
	5	2732			0.9							700
	10	2734.3			0.5	80	70	20.5	260			725
	15½	2736.32			0.1							740

Pump started with Valves wide open.

Particle Size Determination

Test: Andersen -1 Date: 5/27/76

Plate	Tare(g)	Final(g)	Net(mg)	Filter Net	Total	% of Total	Cum %	average ECD (Microns)
1	0.1564	0.1571		0.7		2.0	2.0	15.4 & abov
2	0.1553	0.1560		0.7		2.0	4.0	9.6
3	0.1480	0.1489		0.9		2.6	6.6	6.4
4	0.1507	0.1515		0.8		2.3	8.9	5.0
5	0.1433	0.1444		1.1		3.2	12.1	2.8
6	0.1548	0.1635		8.7		25.3	37.4	1.4
7	0.1458	0.1554		9.6		27.9	65.3	.88
8	0.1536	0.1612		7.6		22.1	87.4	.59
Back Up Filter	0.2107	0.2150		4.3		12.6	100.0 <	.59
		Total		34.4		100.0		

Test: Andersen - 2 Date: 5/27/76

Plate	Tare(g)	Final(g)	Net(mg)	Filter Net	Total	% of Total	Cum %	average ECD (Microns)
1	0.1489	0.1500		1.1		3.4	3.4	17.0
2	0.1546	0.1552		0.6		1.9	5.3	10.7
3	0.1446	0.1453		0.7		2.2	7.5	7.1
4	0.1538	0.1549		1.1		3.4	10.9	5.0
5	0.1455	0.1470		1.5		4.6	15.5	3.1
6	0.1426	0.1467		4.1		12.7	28.2	1.6
7	0.1432	0.1575		14.3		44.1	72.3	1.0
8	0.1417	0.1477		6.0		18.5	90.8	.66
Back Up Filter	0.2162	0.2192		3.0		9.2	100.0 <	.66
		Total		32.4		100.0		

PARTICULATE CLEANUP SHEET

Date: 5/27/76

Plant: Owens Illinois

Run Number: Andersen #1, 2

Location Of Sample Port: A Furnace Stack

Operator: ______

Barometric Pressure: 29.58

Sample Box No. ______

Ambient Temperature 70

Impinger H_2O

Volume After Sampling 252 ml

Impinger Prefilled With 200 ml

Volume Collected 52 ml

Silica Gel

Weight After 543.4 g

Weight Before 538.0 g

Moisture Weight 5.4 g Moisture Total 57.4 g

Dry Probe and Cyclone Catch:

Container No. ______

Extra No. ______ Weight Results ______ g

Probe, Cyclone, Flask
And Front Of Filter
Acetone Wash:

Container No. ______

Extra No. ______ Weight Results ______ g

Filter Papers and Dry Filter Particulate

Filter No.	Container No.	Filter No.	Container No.
Backup ##11		Backup ##	
Filters 2 ::		Filters 3 :::	

Filter Particulate Weight 0.0668 g

Total Particulate Weight 0.0668 g

% Moisture By Volume $V_{m\,std} = 0.0334\,(19.09)(1.01)\left(29.58 + \frac{.83}{13.6}\right) = 19.09$

$V_{w\,std} = 0.0474\,(57.4) = 2.72$

$\%M = 100 \times \frac{2.72}{2.72 + 19.09} = 12.5\%$

$C_s = 2.205 \times 10^{-6} \times \frac{66.8}{19.09} = 7.72 \times 10^{-6}$ lb/scf

$C_E = 7.72 \times 10^{-6}\,(692\,584) = 5.3$ lb/hr using average flow rate

SOURCE TEST REPORT
GENERAL MOTORS ASSEMBLY PLANT
ST. LOUIS, MISSOURI
SULFURIC ACID MIST METHOD EVALUATION

TABLE OF CONTENTS

PAGE

SUMMARY 160

1.0 INTRODUCTION 161

2.0 SAMPLE RUNS 163

3.0 RESULTS 164

4.0 DISCUSSION 166

APPENDIX - CALCULATIONS AND FIELD DATA 168

FIGURES

PAGE

FIGURE 1 - SULFURIC ACID MIST SAMPLING TRAIN 162

TABLES

PAGE

TABLE 1 TEST RESULTS 164

TABLE 2 TEST RESULTS 165

TABLE 3 COIL RINSINGS VERSUS TOTAL RESULTS 165

SUMMARY

In conjunction with the Regional Air Pollution Study (RAPS) a limited source testing program is being conducted. This report details the results of method evaluation field work related to sulfuric acid mist measurement.

The stack testing site for this evaluation was the power plant at the General Motors Assembly Plant in St. Louis, Missouri. Tests were performed using EPA Standard Method 8 and the Shell method. In addition a comparison was made using a glass-lined probe versus a stainless steel probe.

The results of these tests indicate that a short glass-lined probe should be used where possible and the Shell method yielded results comparable to EPA Method 8. However, the results are inconclusive as to which method is best. The ratio of sulfuric acid to sulfur dioxide ranged from 1.53 to 2.93 percent.

We acknowledge and appreciate the excellent cooperation we obtained from the engineering department and the power plant personnel at General Motors.

1.0 INTRODUCTION

Currently, sampling for sulfuric acid mist is routinely performed as part of the stack testing program under RAPS. Recent work by Hamil (1) and Hillenbrand (2) have given rise to doubts of both accuracy and reproducibility of EPA Standard Method 8 (Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions From Stationary Sources). For this reason the Shell method was used in all testing to date. This method was first described by Goksøyr and Ross (3) and subsequently verified by Lisle and Sensenbaugh (4).

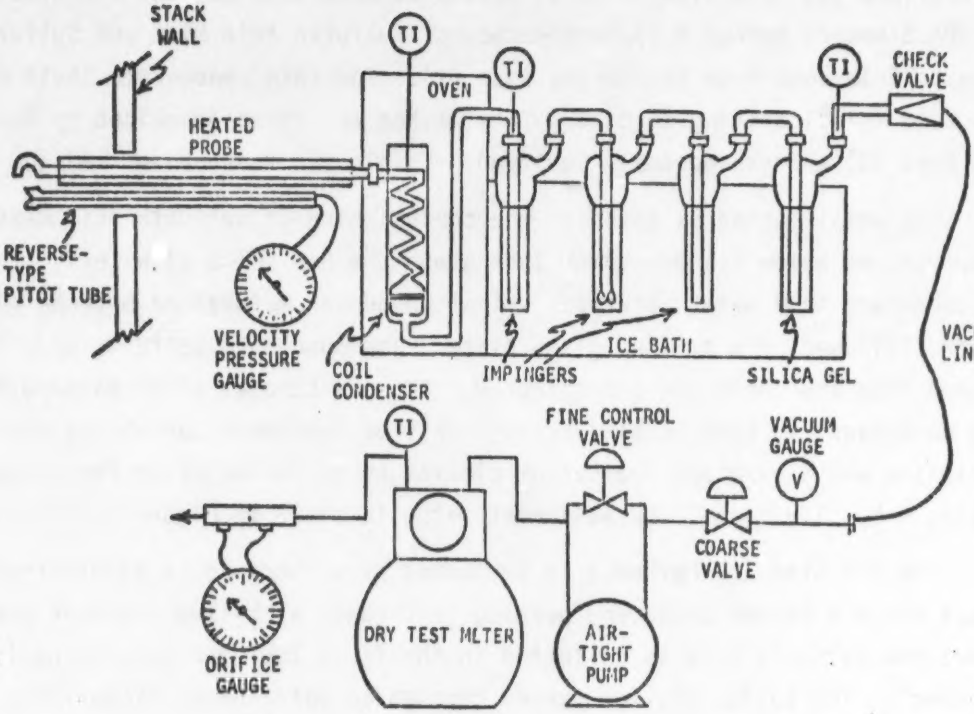
The Shell method is based on the condensation of sulfuric acid mist at temperatures below its dew point (but above the dew point of water). The acid is condensed in a water jacketed, spiral condenser maintained between 140° and 194°F, followed by a fritted glass plate. The condensed sulfuric acid is water washed from the condenser and titrated. The gas sample, after passing through the condenser, is then bubbled through chilled impingers containing hydrogen perioxide which oxidizes the sulfur dioxide to sulfur trioxide for subsequent analysis by titration. The equipment setup is shown in Figure 1.

The EPA Standard Method 8 is performed by withdrawing a sample from a stack using a heated probe and passing it through a chilled impinger train where the sulfuric acid is collected in the first impinger containing isopropanol. The sulfur dioxide passes through an entrainment filter into two impingers containing hydrogen perioxide where it is oxidized and subsequently titrated with barium chloride using a thorin indicator.

This test was run to compare the results obtained by using Method 8 versus the results from the Shell method. In addition, tests were run using the Shell method to compare the results obtained by sampling with a glass-lined probe versus a stainless steel probe and with and without a glass wool filter plug inserted in the probe to remove particulates.

Testing was performed on a coal-fired boiler at the General Motors Assembly Plant in St. Louis. The tests were conducted on 31 August and 1 and 2 September 1976.

For these tests a single sampling point was chosen and used for all tests.


STACK WALL
TI
OVEN
TI
TI
CHECK VALVE
HEATED PROBE
REVERSE-TYPE PITOT TUBE
VELOCITY PRESSURE GAUGE
COIL CONDENSER
IMPINGERS
ICE BATH
SILICA GEL
VACUUM LINE
TI
FINE CONTROL VALVE
VACUUM GAUGE
V
COARSE VALVE
ORIFICE GAUGE
DRY TEST METER
AIR-TIGHT PUMP

Reproduced from best available copy.

FIGURE 1

SULFURIC ACID MIST SAMPLING TRAIN

2.0 SAMPLE RUNS

The first four tests were run with the Shell method using different probes. Tests 1 and 2 were run using a 5 foot, glass-lined probe. A glass wool plug was inserted into the back end of the probe on test number 2. This is the procedure which was normally used on all previous tests. Tests 3 and 4 were run using a 10 foot stainless steel probe. A glass wool plug was inserted into the back end of the probe on both tests. This procedure was tried since this was how one test had to be performed when the glass probe was not available.

Tests 5 through 8 were run to compare Method 8 and the Shell method. Tests 5, 6 and 7 were run using Method 8. The glass-lined probe was used, followed by a flexible, heated Teflon sample line. This was then followed by the ice bath with impingers for collection of the sulfuric acid and sulfur dioxide. Runs 5 and 6 did not have a glass wool plug in the probe since this is not indicated in Method 8. Run 7 was made with a glass wool plug in the flexible heated line. Run 8 was made using the Shell method for comparison.

Tests 9, 10 and 11 were all run using the glass-lined probe and the Shell method. On test 9 a glass wool plug was inserted in the back end of the probe. On test 10 the glass wool plug was inserted in the front end of the probe such that it would be in the end of the probe at stack temperature. Finally, test 11 was run without a glass wool plug.

After all tests, the probe was rinsed and brushed clean and the rinses were subsequently titrated for sulfuric acid. The Shell coil was rinsed and dried after each test. With the exception of the SO_2 impingers on tests 9, 10, and 11, all the impingers were emptied and re-filled for each test. On the last three test runs the SO_2 impingers were not changed between tests but were allowed to accumulate and the results were averaged over the three runs.

3.0 RESULTS

The results of all eleven tests are given in Table 1. The data is reported in units of pounds per cubic foot since this avoids the additional possible error in calculating stack gas flow rate. For illustration purpose Table 2 presents the results in units of pounds per hour. The flow rates used for the results in Table 2 were determined by a stoichiometric calculation of the stack gases based upon fuel composition and Orsat gas analysis.

TABLE 1

TEST RESULTS

Test	H_2SO_4 lb/scf	SO_2 lb/scf	Steam Load lb/hr	Comments
1	6.44×10^{-6}	2.77×10^{-4}	65×10^{3}	Shell meth., Glass Probe, no glass wool
2	7.02×10^{-6}	2.47×10^{-4}	63×10^{3}	Shell meth., Glass Probe, glass wool
3	3.97×10^{-6}	2.41×10^{-4}	61×10^{3}	Shell meth., S.S. Probe, glass wool
4	3.91×10^{-6}	2.10×10^{-4}	52×10^{3}	Shell meth., S.S. Probe, glass wool
5	5.08×10^{-6}	3.33×10^{-4}	50×10^{3}	Meth. 8, Glass + Flex, no glass wool
6	4.60×10^{-6}	3.00×10^{-4}	45×10^{3}	Meth. 8, Glass + Flex, no glass wool
7	5.94×10^{-6}	2.89×10^{-4}	45×10^{3}	Meth. 8, Glass + Flex, glass wool
8	3.94×10^{-6}	1.58×10^{-4}	35×10^{3}	Shell meth., Glass Probe, glass wool
9	3.85×10^{-6}	1.89×10^{-4}	50×10^{3}	Shell meth., Glass Probe, glass wool stack end
10	4.31×10^{-6}	1.89×10^{-4}	50×10^{3}	Shell meth., Glass Probe, glass wool oven end
11	5.53×10^{-6}	1.89×10^{-4}	45×10^{3}	Shell meth., Glass Probe, no glass wool

TABLE 2

TEST RESULTS

Test	Steam Load lb/hr	Coal Rate lb/hr	Calc. Flow Rate SCFH	H_2SO_4 lb/hr	SO_2 lb/hr
1	65×10^3	6989	1114301	7.2	309
2	63×10^3	6774	1080022	7.6	267
3	61×10^3	6559	1045743	4.2	252
4	52×10^3	5591	891409	3.5	195
5	50×10^3	5376	844462	4.3	281
6	45×10^3	4839	760110	3.5	228
7	45×10^3	4839	760110	4.5	220
8	35×10^3	3763	591092	2.3	93
9	50×10^3	5376	844462	3.3	160
10	50×10^3	5376	844462	4.2	160
11	45×10^3	4839	760110	4.2	144

Table 3 is included to illustrate the effect of the probe in collecting some of the acid mist. The coil rinsings and the probe washes were analyzed separately.

TABLE 3

COIL RINSINGS VERSUS TOTAL RESULTS

	H_2SO_4			
Test	Coil Cond.	Total	% in Coil	Comment
1	5.27×10^{-6}	6.44×10^{-6}	81.8	Glass Probe, no glass wool
2	3.50×10^{-6}	7.02×10^{-6}	49.9	Glass Probe, glass wool - oven end
3	1.25×10^{-6}	3.91×10^{-6}	31.5	S.S. Probe, glass wool - oven end
4	1.19×10^{-6}	3.91×10^{-6}	30.4	S.S. Probe, glass wool - oven end
8	1.71×10^{-6}	3.94×10^{-6}	43.4	Glass Probe, glass wool - oven end
9	2.21×10^{-6}	3.85×10^{-6}	57.4	Glass Probe, glass wool - stack end
10	1.69×10^{-6}	4.31×10^{-6}	39.2	Glass Probe, glass wool - oven end
11	3.22×10^{-6}	5.53×10^{-6}	58.2	Glass Probe, no glass wool

4.0 DISCUSSION

As the data in Table 1 indicates for tests 5 through 8, there is little apparent difference between the results from the Shell method and EPA Method 8. The results are lower on test 8, however the load was also lower during that test, by the same percentage. Unfortunately, not enough test runs were made under similar conditions to provide any clear decision as to which method may be better. Since a better method was not singled out, tests will continue to be run using the Shell method.

The results comparing the glass probe and the stainless steel probe are much more helpful. As seen in Table 1 the results are clearly 33% lower with the stainless probe. This is possibly caused by a shift in the equilibrium between SO_3 and SO_2 in the presence of the metal probe or corrosion of the probe. The mechanism is uncertain but the indications are that the stainless steel probe should be avoided.

The extra length of the stainless probe may be the reason for the greater retention of the acid in the probe as shown in Table 3. Also, the metal surface may be the reason again. In either case the mechanism is again not clearly known from the tests performed but the indications are that the shorter glass probe should be used wherever possible. The results in Table 3 also emphasize the need to rinse the probe thoroughly since half the sample ends up in the probe and glass wool plug.

The glass wool plug is needed to keep the coil condenser clear of particulate for sources which may be heavy in particulates. As the results indicate in Table 3, the glass wool plug should be inserted in the probe at the stack end, just after the nozzle. This placement keeps the glass wool at stack temperature rather than probe temperature and lessens the chance of absorbing acid mist on the glass wool.

REFERENCES

1. Hamil, H. F., et al, "Collaborative Study of EPA Method 8 (Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions from Stationary Sources)", EPA 650/4-75-003.
2. Hillenbrand, et al, "Chemical Composition of Particulate Air Pollutants from Fossil-Fuel Combustion Sources", Batlelle Columbus Labs, March 1973, EPA-R2-73-216, PB219.009.
3. Goksøyr, H., and K. Ross, "Determination of Sulphur Trioxide in Flue Gases", J. Inst. Fuel V35, p. 177 (1962).
4. Lisle, E. S. and J. D. Sensenbaugh, "Determination of Sulfur Trioxide and Acid Dew Point in Flue Gases", Combustion 36, 12, (1965).

APPENDIX

CALCULATIONS AND FIELD DATA

STOICHIOMETRIC

FLOW RATE CALCULATION

BOILER #2

Coal Composition: 9/1/76

Moisture 11.25%

Ash 12.89

S 3.51 ÷ 32 = 0.11 x 1 = 0.11

C 60.45 ÷ 12 = 5.04 x 1 = 5.04

H_2 4.0 ÷ 2 = 2.0 x 0.5 = 1.00

N_2 1.0 ÷ 28 = 0.04

O_2 6.9 ÷ 32 = 0.22 x -1 = -.22

5.93 mols O_2 required

@ 46.6% excess air 2.76

8.69

$N_2 = 3.76 \times O_2$ = 32.67

Mols Dry Flue Gas = $CO_2 + SO_2 + N_2$ + excess $O_2 + N_2$ =
5.04 + 0.11 + 0.04 + 2.76 + 32.67 = 40.62 mols/100# coal

50.62 x 386.7 = 15708 SCF/100# coal

For Test 5: 5376 lb. coal/hr.
= 53.76 x 15708 = 844462 SCFH

SUPPLEMENTARY PROCESS DATA FOR POWER PLANTS

Date	8/31	9/1	9/2	
Net Unit Load - MW				
Average Steam Load - 10^3 lb/hr				
Boiler Heat Input				
Fuel Burning Rate - lb/hr				
Fuel Heating Value - BTU/lb	10557	10646	10646	
Fuel Sulfur Content - %	3.18	3.51	3.51	
Fuel Ash Content - %	12.01	12.89	12.89	
Fuel Moisture Content %	11.57	11.25	11.25	

	Time	Coal Scale	Steam Chart	Steam Pres.
8/31	10:00	154608	68,000	165
	11:20	154648	63,000	165
	12:00	ı	64,000	165
	1:25	154723	61,000	165
	2:32	154763	52,000 Δ@2:15	170
9/1	9:45	155276	53,000	165
	11:00	155305	45,000	165
	12:15	155330	46,000	165
	1:30	155356	42,000	167
	1:55		34,000	165
	2:00	155369	42,000	165
9/2	9:15	155727	49,000	165
	11:20	155781	53,000	165
	12:35	155811	46,000	165
	1:25	155830	42,000	165

ORSAT FIELD DATA

Location General Motors - Blr 2 Comments:

Date 8/31, 9/1/76

Time

Operator

Test	(CO_2) Reading 1	(O_2) Reading 2	(CO) Reading 3
8-31 10:45	7.2	7.8	0
1:15	7.8	9.0	0
1:45	8.2	9.5	0
9-1 10:10	6.6	7.8	0
10:25	6.5	7.7	0
10:45	6.5	7.3	0
11:00	6.4	7.5	0
11:15	7.0	7.2	0
11:30	5.2	6.0	0
1:50	6.4	7.4	0

8/31 Excess Air = $100 \times \frac{8.8}{(.266 \times 83.5) - 8.8} = 65.6\ \%$

9/1 Excess Air = $100 \times \frac{7.3}{(.266 \times 86.3) - 7.3} = 46.6\ \%$

ORSAT FIELD DATA

Location General Motors - Blr 2 Comments:

Date 9/2/76

Time

Operator

Test	(CO_2) Reading 1	(O_2) Reading 2	(CO) Reading 3
9.2 10:20	7.4	6.8	0
10:40	6.4	6.6	0
11:00	5.8	5.6	0

Excess Air $= 100 \times \frac{6.3}{(.266 \times 87.2) - 6.3} = 37.3\%$

H_2SO_4 MIST and SO_2 EMISSION DATA

					Probe	Glass wool
Date	8/31	8/31	8/31	8/31	8/31	8/31
Run No.	1	1	2	2	1 + 2	2
V_{mc}-Meter Volume, Ft^3	10.89		10.18		21.07	10.18
Vmstd-Meter Volume, Std. Cond.	10.835		10.13		20.966	10.13
P_B-Barometric Pressure, "Hg	29.49		29.49		29.49	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.1		0.1		0.1	
V_t-Vol. of Titrant, ml.	5.4	8.7	3.35	7.25	4.65	2.25
V_{tb}-Vol. of Titrant for Blank, ml.	-	-	-	-	-	-
V_{soln}-Vol. of Solution, ml.	100	500	100	500	100	100
V_a-Vol. of Aliquot, Titrated, ml.	10	1.0	10	1.0	10	10
lb/scf H_2SO_4 $\times 10^{-6}$	5.27		3.50		2.35 ~~1.14~~	2.35
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$		2.77		2.47		
lb/10^6 Btu SO_2						

$$V_{mstd} = 0.0334\,(V_m)\,CF\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{\text{lb-l}}{\text{g-ml}}\right)(V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{\text{lb-l}}{\text{g-ml}}\right)(V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

H_2SO_4 MIST and SO_2 EMISSION DATA

					Probe	Glass Wool
Date	8/31	8/31	8/31	8/31	8/31	8/31
Run No.	3	3	4	4	3 & 4	3 & 4
V_{mc}-Meter Volume, Ft^3	10.24		10.30		10.54	
Vmstd-Meter Volume, Std. Cond.	10.189		10.249		10.439	
P_B-Barometric Pressure, "Hg	29.49		29.49		29.49	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.1		0.1		0.1	
V_t-Vol. of Titrant, ml.	1.2	7.1	1.15	6.5	6.0	3.0
V_{tb}-Vol. of Titrant for Blank, ml.	-	-	-	-	-	-
V_{soln}-Vol. of Solution, ml.	100	500	100	500	250	100
V_a-Vol. of Aliquot, Titrated, ml.	10	1.0	10	1.0	20	10
lb/scf H_2SO_4 $\times 10^{-6}$	1.25		1.19		3.88	1.55
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-9}$		2.41		2.19		
lb/10^6 Btu SO_2						

$$\text{Vmstd} = 0.0334\ (V_m)\ CF \left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{\text{lb-l}}{\text{g-ml}}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{\text{lb-l}}{\text{g-ml}}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

H_2SO_4 MIST and SO_2 EMISSION DATA

Date	9/1	9/1	9/1	9/1	9/1	9/1
Run No.	5	5	6	6	7	7
V_{mc}-Meter Volume, Ft^3	10.46		10.38		10.01	
Vmstd-Meter Volume, Std. Cond.	10.364		10.284		9.917	
P_B-Barometric Pressure, "Hg	29.36		29.36		29.36	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.16		0.14		0.13	
V_t-Vol. of Titrant, ml.	3.35	20.0	2.95	17.89	3.85	16.6
V_{tb}-Vol. of Titrant for Blank, ml.	-	-	-	-	-	-
V_{soln}-Vol. of Solution, ml.	250	250	250	250	250	250
V_a-Vol. of Aliquot, Titrated, ml.	20	1.0	20	1.0	20	1.0
lb/scf H_2SO_4 $\times 10^{-6}$	4.28		3.80		5.14	
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$		3.33		3.00		2.89
lb/10^6 Btu SO_2						

$$Vmstd = 0.0334\ (Vm)\ CF\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$CH_2SO_4 = \frac{\left(1.08 \times 10^{-4}\ \frac{lb\text{-}l}{g\text{-}ml}\right)(V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = lb/scf$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{lb\text{-}l}{g\text{-}ml}\right)(V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = lb/scf$$

H_2SO_4 MIST and SO_2 EMISSION DATA

	Probe, Glass Wool			Probe, Glass Wool		Probe, Glass Wool
Date	9/1	9/1	9/1	9/1	9/2	9/2
Run No.	5,6,7	8	8	8	9	9
V_{mc}-Meter Volume, Ft^3	30.85	10.29			10.33	
Vmstd-Meter Volume, Std. Cond.	30.565	10.198			10.303	
P_B-Barometric Pressure, "Hg	29.36	29.37			29.56	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.14	0.1			0.1	
V_t-Vol. of Titrant, ml.	5.55	1.65	4.65	4.3	4.3	3.2
V_{tb}-Vol. of Titrant for Blank, ml.	-	-	-	-	-	-
V_{soln}-Vol. of Solution, ml.	250	100	500	100	100	100
V_a-Vol. of Aliquot, Titrated, ml.	20	10	1.0	20	20	20
lb/scf H_2SO_4 $\times 10^{-6}$	2.40	1.71		2.23	2.21	1.64
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$			1.58			
lb/10^6 Btu SO_2						

$$\text{Vmstd} = 0.0334\ (\text{Vm})\ \text{CF}\left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$C_{H_2SO_4} = \frac{\left(1.08 \times 10^{-4}\ \frac{\text{lb-l}}{\text{g-ml}}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5}\ \frac{\text{lb-l}}{\text{g-ml}}\right)\ (V_t - V_{tb})\ (\underline{N})\ \left(\frac{V_{soln}}{V_a}\right)}{V_{mstd}} = \text{lb/scf}$$

H_2SO_4 MIST and SO_2 EMISSION DATA

		Probe, Glass Wool		Probe		
Date	9/2	9/2	9/2	9/2	9/2	
Run No.	10	10	11	11	9,10,11	
V_{mc}-Meter Volume, Ft^3	9.72		9.90		29.95	
Vmstd-Meter Volume, Std. Cond.	9.692		9.858		29.853	
P_B-Barometric Pressure, "Hg	29.55		29.51		29.54	
ΔH-Avg. Orifice Pres. Drop, "H_2O	0.1		0.1		0.1	
V_t-Vol. of Titrant, ml.	3.1	2.8	6.0	4.8	16.35	
V_{tb}-Vol. of Titrant for Blank, ml.	-	-	-	-	-	
Vsoln-Vol. of Solution, ml.	100	250	100	100	500	
V_a-Vol. of Aliquot, Titrated, ml.	20	20	20	20	1.0	
lb/scf H_2SO_4 $\times 10^{-6}$	1.69	2.62	3.22	2.31		
lb/10^6 Btu H_2SO_4						
lb/scf SO_2 $\times 10^{-4}$					1.89	
lb/10^6 Btu SO_2						

$$Vmstd = 0.0334\ (Vm)\ CF \left(P_B + \frac{\Delta H}{13.6}\right)$$

CF_m = Meter correction factor

$$CH_2SO_4 = \frac{\left(1.08 \times 10^{-4} \frac{lb\text{-}l}{g\text{-}ml}\right) (V_t - V_{tb})\ (\underline{N}) \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = lb/scf$$

$\underline{N}$ = 0.01 Normal Barium Perchlorate

$$C_{SO_2} = \frac{\left(7.05 \times 10^{-5} \frac{lb\text{-}l}{g\text{-}ml}\right) (V_t - V_{tb})\ (\underline{N}) \left(\frac{V_{soln}}{Va}\right)}{V_{mstd}} = lb/scf$$

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 8/31

Plant GM   Location #2 Blr.

Bar. Pressure 29.49 "Hg   Comments: 3 feet into duct

Ambient Temp 90 °F   1/4 in. nozzle

Run No 1

Power Stat Setting ______

Filter Used: Yes ______ No ______

Operator ______

Clock Time	Meter (Ft.³)	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
10:10								
0	2891.98	0.13	0.1	410	320	174	180	90
10	2894.5	0.13	0.1		350	176	160	80
20	2896.9	0.12	0.1		380	172	140	75
30	2899.27	0.13	0.1		330	166	130	78
40	2901.65	0.12	0.1		345	160	120	80
45	2902.87							

Comments: no glass wool plug

Reproduced from best available copy.

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 8/31

Plant GM Location Blr #2

Bar. Pressure 29.49 "Hg Comments: 1/4 in. nozzle

Ambient Temp 90 °F

Run No 2

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
11:25 0	2902.87							
5	2904.1	0.12	0.1	400	318	169	125	82
15	2906.4	0.13	0.1		340	162	120	80
25		0.13	0.1		340	156	120	80
35		0.13	0.1		340	175	200	85
45	2913.05							

Comments: glass wool plug used.

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 8/31

Plant GM Location Blr #2

Bar. Pressure "Hg Comments: Stainless Probe

Ambient Temp 90 °F Glass wool plug

Run No 3 Probe temp. doesn't work - left at high setting.

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
1:00 0	2913.05	0.13	0.1	420			100	80
15	2916.6	0.13	0.1	420		140	180	80
35	2921.05	0.15	0.1	430		178	210	80
45	2923.29							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 8/31

Plant GM

Location Blr #2

Bar. Pressure ________ "Hg

Comments: Stainless Probe
Glass wool plug

Ambient Temp 90 °F

Run No 4

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______________________

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
2:30 0	2923.29	0.09	0.1	400		148	150	80
25	2929.3	0.09	0.1	400		154	120	80
35	2931.3	0.08	0.1	400		150	110	80
45	2933.59							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 9/1

Plant GM

Location Blr #2

Bar. Pressure ______ "Hg

Comments: Method 8
1/4 in. nozzle
Flex line heated to 338°F

Ambient Temp 90 °F

Run No 5

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F Stack	Probe	Coil	Impinger In	Out
9:50 0	2933.60	0.1	0.14		340			
5	2935.2	0.12	0.17	380	360			
10								
15	2938.2	0.13	0.18		355			
25	2941.2	0.1	0.15		345			
35	2944.06							

Comments: after sampling, disconnected between probe & flex line and pulled air through for 4 min.; 2 cft.

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 9/1

Plant GM   Location Blr #2

Bar. Pressure 29.36 "Hg   Comments: Method 8

Ambient Temp 90 °F

Run No 6

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______________________

Clock Time	Meter (Ft.³)	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger In	Impinger Out
10:55 0	2946.00	0.10	0.14		355			
15	2950	0.10	0.14	365	355			
20	2952.5	0.1	0.14		360			
35	2955.0	0.1	0.14	365	360			
40	2956.38							

Comments: after sampling, pulled air Through for 4 min.

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 9/1

Plant GM

Location Blr #2

Bar. Pressure 29.36 "Hg

Comments: Method 8
Glass wool plug in heated line

Ambient Temp 90 °F

Run No 7

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
12:10 0	2957.77	0.09	0.13		340			
10	2960.7	0.09	0.13	365	350			
20	2963.5	0.09	0.13	370	340			
30	2966.4	0.09	0.13					
35	2967.78							

Comments: After sampling, pulled air through for 4 min.

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 9/1

Plant GM Location Blr #2

Bar. Pressure 29.37 "Hg Comments: Shell Method

Ambient Temp 90 °F Glass wool in oven end of probe.

Run No 8

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter ($Ft.^3$)	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
1:30 0	2969.20	0.08	0.1		355	152		
10	2971.6	0.08	0.1	360	370	166		
25	2975.2	0.07	0.1	360	350	176		
40	2978.6	0.07	0.1	360	345	166		
44	2979.49							

Comments:

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 9/2

Plant GM

Location Blr #2

Bar. Pressure 29.56 "Hg

Comments: Shell Method
Glass wool plug in stack end of probe

Ambient Temp 85 °F

Run No 9

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______________________

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
9:47 0	2979.52	0.08	0.1	380	325	166		
10	2982	0.14	0.1	385	335	168	160	80
15	2983.1	0.13	0.1	390	345			
25	2985.5	0.12	0.1	390	340	162		
35	2987.7	0.12	0.1	390	350	159		
45	2989.85							

Comments: SO_2 impingers not changed after run.

GAS SAMPLING FIELD DATA

Material Sampled For SO3

Date 9/2

Plant GM

Location Blr #2

Bar. Pressure 29.55 "Hg

Comments: Shell method

Glass wool plug in oven end of probe.

Ambient Temp 90 °F

Run No 10

Power Stat Setting

Filter Used: Yes No

Operator

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
11:12 0	2989.85	0.09	0.1	385	325	142		
5	2991.05	0.13	0.1		355	145		
15	2993.3	0.10	0.10		350	150		
35	2997.3	0.10	0.1	380	365	150		
45	2998.9	0.12	0.1			154		
50	2999.57							

Comments: To maintain flow, had to open coarse valve wide open vacuum = 13 in Hg, normally only 2 or 3 - after 30 min.

GAS SAMPLING FIELD DATA

Material Sampled For SO_3

Date 9/2

Plant GM Location Blr #2

Bar. Pressure 29.51 "Hg Comments: Shell method no glass wool

Ambient Temp 90 °F

Run No 11

Power Stat Setting ______

Filter Used: Yes ______ No ____

Operator ______________________

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F				
				Stack	Probe	Coil	Impinger	
							In	Out
12:37 0	2999.57	0.09	0.1		325	144		
5	3000.7	0.09	0.1	375	350	146		
15	3003.1	0.08	0.1	375	355	148		
25	3005.2	0.08	0.1	375	355	148		
40	3008.4	0.08	0.1	375	375	152		
45	3009.47							

Comments:

SOURCE TEST REPORT
CHRYSLER MOTORS ASSEMBLY PLANT
ST. LOUIS, MISSOURI
BOILER NO. 1

TABLE OF CONTENTS

		PAGE
SUMMARY		192
1.0	INTRODUCTION	193
2.0	PROCESS DESCRIPTION	194
3.0	PROCESS OPERATION	195
4.0	SOURCE TEST DESCRIPTION	196
5.0	SAMPLING AND ANALYTICAL PROCEDURES	197
6.0	RESULTS AND DISCUSSION	198
	APPENDIX - CALCULATIONS AND FIELD DATA	199

TABLES

PAGE

TABLE 1 SUMMARY OF RESULTS 198

SUMMARY

In conjunction with the RAPS project, a limited stack testing program is being conducted. This report details the results obtained on boiler no. 1 at the Chrysler Motors Assembly Plant in St. Louis, Missouri.

Stack testing was performed for measuring nitrogen oxides since this was the major pollutant for this natural gas-fired boiler. Results of these tests are included in this report. The results of these tests compared very well with those predicted from published EPA emission factors: 17.8 pounds per hour versus 17.4 pounds per hour, respectively.

We acknowledge and appreciate the excellent cooperation we obtained from the management and the power plant personnel at Chrysler.

1.0 INTRODUCTION

The current stack testing program is being conducted in conjunction with the emission inventory work for the St. Louis RAPS project. The emission inventory is being compiled using published emission factors. The stack testing is being conducted to develop special plant emission factors and thereby improve the RAPS emission inventory.

This stack test was conducted at the Chrysler Motors Assembly Plant in St. Louis, Missouri. Testing was performed on boiler no. 1 on 12 May 1976.

Boiler no. 1 is a gas-fired, 90,000 pounds per hour steam generating unit. There is no collection equipment on this unit. The boiler was tested for nitrogen oxides, CO_2 and O_2.

2.0 PROCESS DESCRIPTION

Boiler no. 1 was built by Wickes Boiler Co. in 1958. It was originally installed with a Laclede Stoker for coal-firing and was subsequently converted to gas-firing. Steam pressure is maintained at approximately 150 psi. The steam is used for heating within the assembly plant. The capacity of this boiler is rated at 90,000 pounds of steam per hour.

This boiler is an induced draft unit with a fan rated at 69,200 cubic feet per minute. The stack is of steel construction and is 125 feet tall and 5.5 feet inside diameter at the exit.

3.0 PROCESS OPERATION

Boiler no. 1 was tested on 12 May 1976. During the testing period boiler no. 2 was shut down in order that all the natural gas used in the powerhouse would be used in boiler no. 1. This enabled the measuring of the amount of gas burned during testing. The steam load remained fairly constant during testing.

4.0 SOURCE TEST DESCRIPTION

Boiler no. 1 was tested near the base of the stack, just after the induced draft fan. At this point there is an opening into the stack which was previously used for measuring static pressure.

This position is extremely turbulent and is unsuitable for particulate testing or velocity measurements. However, for gaseous sampling, this location is adequate. Since Pitot measurements could not be taken, the flow of stack gases was calculated using fuel consumption figures.

5.0 SAMPLING AND ANALYTICAL PROCEDURES

The stack gas concentrations of CO_2, oxygen, CO and nitrogen by difference were measured with a standard Orsat apparatus. These concentrations and the moisture content were used to determine molecular weight of the stack gas.

Moisture content was determined by passing a measured amount of gas through cooled impingers containing a known volume of deionized water, measuring the increase in the volume of the impinger liquid, and calculating the amount of water vapor in the sample from this increase and the measured amount of gas.

Gas flow rates were calculated using the quantity of gas used, the composition of the gas, and the calculated amount of excess air determined by the Orsat measurements.

5.1 NITROGEN OXIDES

Using EPA Standard Method 7, gas samples were withdrawn from the stack into evacuated 2-litre flasks containing a dilute solution of hydrogen peroxide and sulfuric acid. The hydrogen peroxide oxidizes the lower oxides of nitrogen (except nitrous oxide) to nitric acid. The resultant solution is evaporated to dryness and treated with phenol disulfonic acid reagent and ammonium hydroxide. The yellow trialkali salt of 6-nitro-1-phenol-2,4-disulfonic acid is formed, which is measured colorimetrically.

6.0 RESULTS AND DISCUSSION

The nitrogen oxide emissions averaged 17.8 pounds per hour, as NO_2. Since this test was performed in conjunction with an emission inventory, it is of interest to note how closely the results compare with those predicted from emission factors. Using a factor of 230 pounds NO_2 per million cubic feet burned from the EPA publication, AP-42, "Compilation of Air Pollutant Emission Factors", the predicted amount of nitrogen oxides is 17.4 pounds per hour.

The results of this test are summarized in Table 1. Detailed calculations and field data are given in the Appendix.

TABLE 1

SUMMARY OF RESULTS

Stack Flow Rate - SCFM, dry	15,188
% Water Vapor - Vol. %	7.89
% CO_2 - Vol. % dry	9.1
% O_2 - Vol. % dry	5.4
% Excess Air @ Sampling Point	31.1
NO_X Emissions - lbs/10^6 Btu	0.23
lbs/hr.	17.8

APPENDIX

CALCULATIONS AND FIELD DATA

PARTICULATE CALCULATIONS

Volume of dry gas sampled at standard conditions - 70^{o} F, 29.92 "Hg

$$V_{mstd} = V_m \, CF_m \left(\frac{Pm}{P_{std}}\right)\left(\frac{Tstd}{Tm}\right) = 0.0334 \, V_m \, CF_m \left(P_B + \frac{\Delta H}{13.6}\right)$$

Vm_{std} = Volume of dry gas sampled at standard conditions, ft^3

Vm = Meter volume sampled, ft^3

CF_m = Meter correction factor

P_m = Meter pressure, barometric pressure, P_B, plus orifice pressure, ΔH, in. Hg.

Pstd = Standard pressure, 29.92 in. Hg.

Tstd = Standard temperature, 530^{o} R or 70^{o} F

Tm = Meter temperature, 530^{o} R for compensated meter

Volume of water vapor at standard conditions

$$Vw = V1_c \left(\frac{\rho H_2O}{MH_2O}\right)\left(\frac{R \, Tstd}{Pstd}\right) \quad \frac{lb.}{454 \text{ gm.}} \quad = 0.0474 \times V1_c$$

Vw = Volume of water vapor at standard conditions, ft^3

$V1_c$ = Volume of liquid collected in impingers and silica gel, ml.

ρH_2O = Density of water, 1g/ml.

M H_2O = Molecular weight of water, 18 lb/lb mol

R = Ideal gas constant, 21.83 in. Hg. - cu. ft./lb-mol - ^{o}R

% Moisture in Stack Gas

$$\% M = 100 \times \frac{Vw \ std}{Vm_{std} + Vw_{std}}$$

Average molecular weight of dry stack gas

$$MW_D = \left(\%CO_2 \times \frac{44}{100}\right) + \left(\% \; O_2 \times \frac{32}{100}\right) + \left(\% \; N_2 \times \frac{28}{100}\right)$$

Molecular weight of stack gas

$$MW_W = \left(\frac{100 - \% \; M}{100} \times MW_D\right) + \left(\frac{\%M}{100} \times 18\right)$$

Stack velocity at stack conditions

$$V_s = 85.48 \times C_p \left(\frac{Ts \times \Delta P \; avg.}{Ps \times MW_W}\right)^{1/2}$$

V_s = stack velocity, fps.

85.48 = pitot constant, $\frac{ft.}{sec.} \left(\frac{lb.}{lb. \; Mols - {}^oR}\right)^{1/2}$

C_p = pitot coefficient, dimensionless

T_s = average stack temperature, ^oR

P_s = stack pressure, barometric pressure plus static pressure, in. Hg.

ΔP Avg = average differential pressure, in. H_2O

Stack gas volume at standard conditions

$$Qs = 3600\left(1 - \frac{\%M}{100}\right) V_s \; A\left(\frac{Tstd}{Ts} \; \frac{Ps}{Pstd}\right)$$

Q_s = stack gas volume flow rate, SCF/hr

A = stack cross sectional area, ft^2

3600 = seconds per hour

$Qs' = Q_s \div 60$ = SCFM

Excess air at sample point

$$\% EA = \frac{100 \times \% O_2}{(0.266 \times \% N_2) - \% O_2}$$

% EA = excess air at sample point, %

0.266 = ratio of oxygen to nitrogen in air by volume

SAMPLING CALCULATIONS

Test: Chrysler **Date:** 5/12/76

Material collected (mg)

Filter Catch =
Dry Catch =
Acetone Wash =

TOTAL =

Gas Volume $V_{mstd} = 0.0334\ V_m\ CF_m \left(P_B + \frac{\Delta H}{13.6}\right)$

$0.0334\ (22.013)\ (\ 0.97\ ) \left(29.52 + \frac{(-95.2)}{13.6} \right) = \underline{\ 16.061\ }$ SCF

Volume of water vapor $Vw = 0.0474 \times Vlc$

$0.0474\ (\ 29\ \text{ml}) = \underline{\ 1.375\ }$ SCF

% Moisture $\%M = 100 \times \frac{Vwstd}{Vmstd + Vwstd}$

$100 \times \frac{(\ 1.375\ )}{(16.061\ ) + (\ 1.375\ )} = \underline{\ 7.89\ }\ \%$

Molecular Weight of dry stack gas

$MW_D = \%CO2 \times 0.44 + \%O2 \times 0.32 + \%N2 \times 0.28$

$(\ 9.1 \times 0.44) + (\ 5.4 \times 0.32) + (85.5 \times 0.28) = \underline{\ 29.67\ }$

Molecular Weight of stack gas

$MWw = \frac{100 - \%M}{100} \times MW_D + \frac{\%M}{100} \times 18$

$\left[\frac{100 - 7.89}{100} \times 29.67 \right] + \left[\frac{7.89}{100} \times 18 \right] = \underline{\ 28.75\ }$

STOICHIOMETRIC
FLOWRATE CALCULATIONS
Boiler #1

Average fuel composition obtained from Laclede Gas - 23 June 1976

	Vol. %	mols/100 cu.ft.		Combustion mols O_2 req'd	Water free mols flue gas
CO_2	0.5	0.001			0.001
CH_4	95.0	0.246	x 2	0.492	0.246
C_2H_6	3.0	0.008	x 3.5	0.028	0.016
C_3H_8	1.0	0.003	x 5	0.015	0.009
C_4H_{10}	0.5	0.001	x 6.5	0.007	0.004
				0.542	0.276
Excess O_2 @ 31.1%				0.169	
				0.711	
$N_2 = 3.76 \times O_2$				2.673	

Mols Dry Flue Gas = $CO_2 + O_2 + N_2$

$0.276 + 0.169 + 2.673 = 3.118$ mols/100 cu.ft.

@ 70°F $3.118 \times 386.7 = 1205.7$ scf/100 cu.ft.

@ 755.8×10^2 cu.ft./hr. $1205.7 \times 755.8 = 911{,}268$ scf/hr.

$= 15{,}188$ scfm

NO_x EMISSION DATA

Date 12 May 1976

Run No.	1	2	3	4	5	6	7	8
Time	0900	0930	0955	1030	1055	1130	1200	1230
$\mu g\ NO_2$	612	592	100	508	140	632	488	574
T_i- Initial Flask Temp, ^oR	535	535	535	535	535	535	535	535
T_f- Final Flask Temp, ^oR	540	540	540	540	540	540	540	540
V_{fc}- Flask Volume, ml.	2040	2038	2039	2028	2080	2052	2052	2056
P_i- Initial Flask Pres, "Hg	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
P_f- Final Flask Pres, "Hg	29.46	29.46	29.46	29.46	29.46	29.46	29.46	29.46
lb/scf NO_2 $X10^{-5}$	2.11	2.04	0.34	1.76	0.47	2.16	1.67	1.96
$lb/10^6 Btu\ NO_2$	0.25	0.25	0.04	0.21	0.06	0.26	0.20	0.24

$$Vsc = \left(17.71\ \frac{^oR}{in.\ Hg}\right) (Vfc) \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = scf$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5}\ \frac{lb/scf}{\mu g/ml} \left(\frac{\mu g\ NO_2}{Vsc}\right) = lb/scf\ NO_2$$

SUPPLEMENTARY PROCESS DATA FOR POWER PLANTS

Date	5/12/76			
Net Unit Load - MW				
Average Steam Load - 10^3 lb/hr	56			
Boiler Heat Input				
Fuel Burning Rate - lb/hr				
Fuel Heating Value - BTU/lb	1000 BTU/CF			
Fuel Sulfur Content - %				
Fuel Ash Content - %				
Fuel Moisture Content %				

Time	Steam Flow	Steam Press.	Stack Temp.	Bar. Press.
9:20	59×10^3	150 psi	620 °F	29.55 in. Hg.
10:00			610	
10:35	55×10^3	150	600	
11:10	58×10^3	150	600	
12:10	53×10^3	150	570	29.52

Natural Gas Usage

Time	Meter Reading
8:50	569578.4×10^3 CF
10:35	569637.6
11:10	569655.3
12:10	569685.6
	107.2×10^3 CF

Multiplication factor For Different Line Pressure = 2.35

$107.2 \times 2.35 = 251.92 \times 10^3$ CF

@ 3 hrs, 20 min = 75.58×10^3 CF/hour

ORSAT FIELD DATA

Location Chrysler - #1 Boiler Comments:

Date 5/12/76

Time

Operator Klein

Test	(CO_2) Reading 1	(O_2) Reading 2	(CO) Reading 3
0920	9.6	5.0	0.0
1100	9.0	5.2	0.0
1110	8.6	6.0	0.0
avg.	9.1	5.4	0.0

$$\text{Excess Air} = 100 \times \frac{\%O_2}{(.266 \times \%N_2) - \%O_2}$$

$$100 \times \frac{5.4}{(.266 \times 85.5) - 5.4} = 31.1\ \%$$

OXIDES OF NITROGEN FIELD DATA

Date 5/12/76

Plant Chrysler - Blr. #1

Sample Collected By Klein

Field Data

Clock Time	0900	0930	0955	1030	1055	1130	1200	1230
Flask number	1	2	3	4	5	6	7	8
Volume of flask (ml)*	2040	2038	2039	2028	2080	2052	2052	2086
Pressure before sampling in. Hg.	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Pressure after sampling, in. Hg.	29.46	29.46	29.46	29.46	29.46	29.46	29.46	29.46
Flask temperature, °F	75/80				75/80			

* Flask + valve - 25 ml. for absorbing solution

GAS SAMPLING FIELD DATA

Material Sampled For Moisture

Date 5/12/76

Plant Chrysler

Location Blr. #1

Bar. Pressure 29.52 "Hg

Comments: 100 ml. in each impinger initially

Impingers sitting in chilled water

Ambient Temp 88 °F

Run No

Power Stat Setting

Filter Used: Yes ___ No ___

Operator Griscom

Clock Time	Meter (Ft.^{3})	Pitot in. H_2O ΔP	Orifice in H_2O ΔH	Temperatures °F					Vacuum Gage
				Stack	Probe	Coil	Impinger		
							In	Out	
11:36	101.118			590					8 " Hg
11:58	109.445			570					7"
12:03	109.445			570					7"
12:25	123.131			570					7"

Comments: 229 ml. in impingers after test

22.013 cu. ft. sampled

SOURCE TEST REPORT
U.S.S. AGRI-CHEM PLANT
CRYSTAL CITY, MISSOURI
NITRIC ACID UNIT

TABLE OF CONTENTS

PAGE

SUMMARY 214

1.0 INTRODUCTION 215

2.0 PROCESS DESCRIPTION 216

3.0 PROCESS OPERATION 217

4.0 SOURCE TEST DESCRIPTION 219

5.0 SAMPLING AND ANALYTICAL PROCEDURES 220

6.0 RESULTS AND DISCUSSION 221

APPENDIX - CALCULATIONS AND FIELD DATA 223

FIGURES

PAGE

FIGURE 1 - FLOW DIAGRAM OF TYPICAL NITRIC ACID PLANT USING PRESSURE PROCESS 218

TABLES

PAGE

TABLE 1 - NITROGEN OXIDE EMISSIONS 222

SUMMARY

In conjunction with the RAPS project, a limited stack testing program is being conducted. This report details the results obtained on the nitric acid unit at the U.S.S. Agri-Chem plant in Crystal City, Missouri.

The stack testing was performed solely for measuring nitrogen oxides. Results of these tests are included in this report. Although slightly higher, the results of these tests compared very well with those predicted from published EPA emission factors. As a result of these tests, a plant specific emission factor for this source is 60.4 pounds NO_X per ton of 100% acid produced.

We acknowledge and appreciate the excellent cooperation we obtained from the management and plant personnel at U.S.S. Agri-Chem.

1.0 INTRODUCTION

The current stack testing program is being conducted in conjunction with the emission inventory work for the St. Louis RAPS project. The emission inventory is being compiled using published emission factors, however, when possible stack testing is being conducted on major point sources to develop source specific emission factors.

This stack test was conducted at the U.S.S. Agri-Chem plant in Crystal City, Missouri. Testing was performed on the nitric acid unit on 19 October 1976. This nitric acid unit is rated at 290 tons per day of 100% nitric acid. The unit was tested for nitrogen oxides.

2.0 PROCESS DESCRIPTION

The nitric acid unit at U.S.S. Agri-Chem is an old unit and plans are in the works for its replacement. It was constructed approximately thirty years ago as part of the original plant. Originally, ammonia was manufactured at this plant location and used in this unit to manufacture nitric acid which is then used in the manufacture of ammonium nitrate fertilizer. Ammonia is now manufactured elsewhere and shipped in for use in this nitric acid unit.

This unit is similar to the general diagram shown in Figure 1. Air and ammonia are catalytically reacted and the resulting vapor is absorbed to form approximately 59% nitric acid. This unit is rated at 290 tons of acid per day, as 100% acid.

The tail gas stream is split after the final pass through the reactor, before entering the expander. The gases then exit through two 1.5 foot diameter and 50 foot tall stacks. At rated production the gases exit at 12,300 SCFM from each stack.

3.0 PROCESS OPERATION

The acid unit was tested on 19 October. During the testing period the unit was operated at a constant rate. It had been intended that twelve samples would be taken. However, when the tenth sample was started the electric power to the building was momentarily interrupted and the safety interlocks on the unit kicked off and the operators had to shut the unit down, ending our testing.

During sampling, the production rate averaged 243 tons of acid per day, as 100% acid.

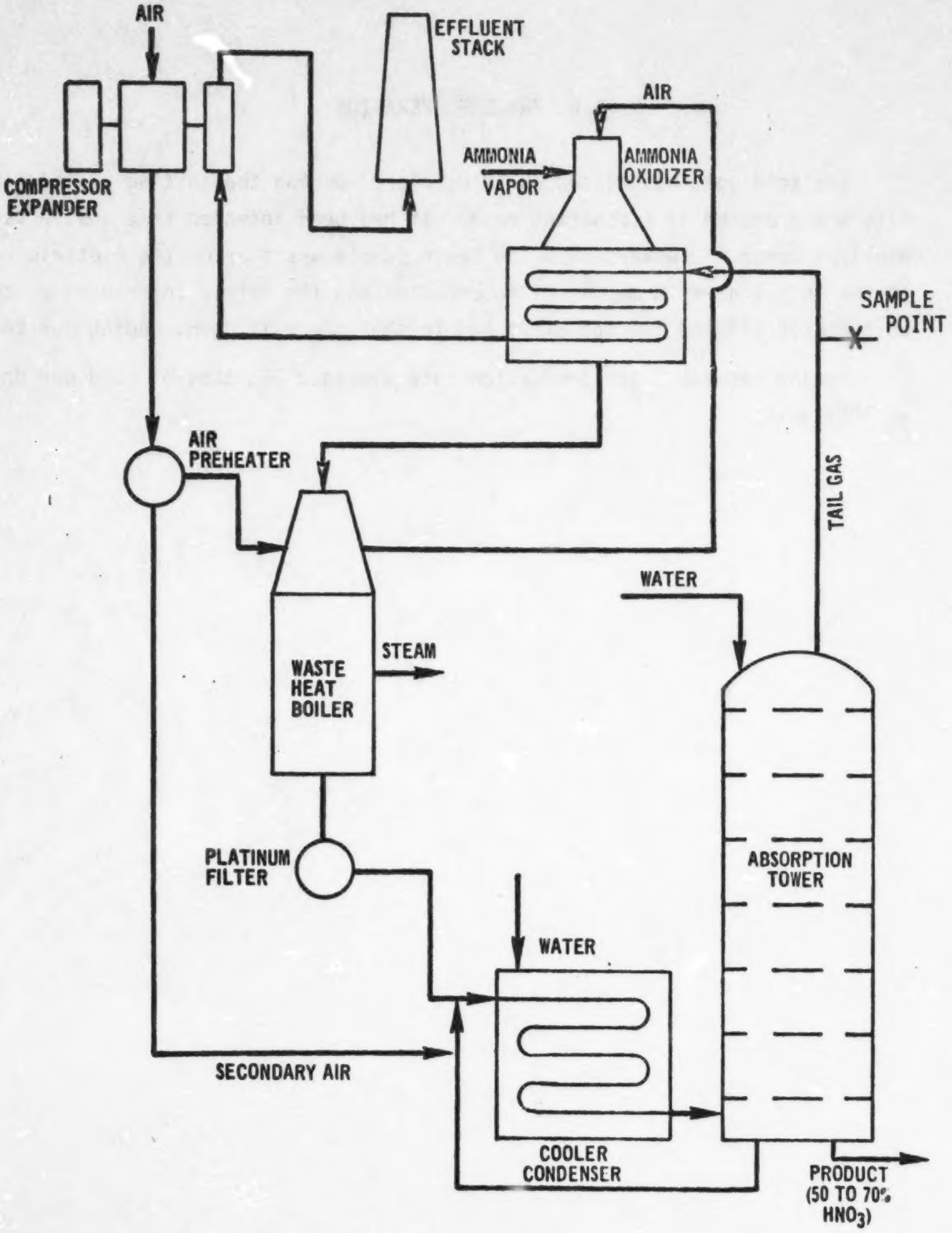

AIR
EFFLUENT STACK
COMPRESSOR EXPANDER
AIR
AMMONIA VAPOR
AMMONIA OXIDIZER
SAMPLE POINT
TAIL GAS
AIR PREHEATER
WATER
STEAM
WASTE HEAT BOILER
ABSORPTION TOWER
PLATINUM FILTER
WATER
SECONDARY AIR
COOLER CONDENSER
PRODUCT (50 TO 70% HNO_3)

FIGURE 1

FLOW DIAGRAM OF TYPICAL NITRIC ACID PLANT USING PRESSURE PROCESS

4.0 SOURCE TEST DESCRIPTION

Due to the high pressure of the system, 100-150 psi., and inaccessability of the stack, a test in the stack was impossible. There is a sample line from the tail gas line prior to entering the preheater section of the reactor, which the operators use to run Orsat and NO_X analyses every other hour. This is the sample point chosen for this test.

Since Pitot measurements could not be made, a design flow rate had to be used and proportionally reduced according to the production rate.

5.0 SAMPLING AND ANALYTICAL PROCEDURES

Gas flow rates were calculated by proportioning the design flow rate for this unit to the ratio of design capacity and actual operating rate. The design rate is simply based upon the air required for reaction with ammonia to form the acid.

5.1 NITROGEN OXIDES

Using EPA Standard Method 7, gas samples were withdrawn from the stack into evacuated 2-litre flasks containing a dilute solution of hydrogen peroxide and sulfuric acid. The hydrogen peroxide oxidizes the lower oxides of nitrogen (except nitrous oxide) to nitric acid. The resultant solution is evaporated to dryness and treated with phenol disulfonic acid reagent and ammonium hydroxide. The yellow trialkali salt of 6-nitro-1-phenol-2, 4-disulfonic acid is formed, which is measured colorimetrically.

6.0 RESULTS AND DISCUSSION

The nitrogen oxide emissions averaged 4.95×10^{-4} pounds per standard cubic foot, or 612 pounds per hour, using the design flow rate. This is slightly higher than the range of 506 - 557 pounds per hour which is obtained by using EPA Emission Factors. This difference is not unexpected considering the age of this acid unit. The results are shown in Table 1.

The flow rate used in the calculations was furnished by plant engineering personnel. This value, 24,600 SCFM, checks with a stoichiometric calculation allowing for a 2% leakage from the system. On the day of testing the production rate was 243 tons per day of 100% acid. At this rate the tailgas flow rate is reduced proportionally to 20,613 SCFM, which was used in the calculations.

The test results agree very well with the measurements made by the operator during the same sampling period. The operator takes a sample, adds peroxide to oxidize the nitrogen oxides to nitrates and titrates the sample with sodium hydroxide. During our testing the operator took three samples with the results: 0.43%, 0.33% and 0.37% as NO_2.

As a result of these tests, a source specific emission factor for this source was determined to be 60.4 pounds NO_X per ton of 100% acid produced.

TABLE 1

NITROGEN OXIDE EMISSIONS

Sample	Time	Emissions, as NO_2		
		lb/scf	ppm	lb/hr
1	10:30A	5.52×10^{-4}	4703	683
2	10:45	5.34×10^{-4}	4550	660
3	11:15	3.94×10^{-4}	3357	487
4	11:30	5.20×10^{-4}	4431	643
5	11:45	4.06×10^{-4}	3459	502
6	12:00	4.69×10^{-4}	3996	580
7	12:15P	5.23×10^{-4}	4456	647
8	1:15	5.22×10^{-4}	4448	646
10	1:30	5.33×10^{-4}	4541	659
			Average =	612

APPENDIX

CALCULATIONS AND FIELD DATA

STOICHIOMETRIC FLOW RATE CALCULATION

$$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$$

$$4\ NO + 2\ O_2 \rightarrow 4\ NO_2$$

$$4\ NO_2 + \frac{4}{3}\ H_2O \rightarrow \frac{8}{3}\ HNO_3 + \frac{4}{3}\ NO$$

$$4\ NH_3 + 7\ O_2 \rightarrow \frac{8}{3}\ HNO_3 + \frac{4}{3}\ NO + \frac{14}{3}\ H_2O$$

290 ton/day HNO_3 = 24166.7 lb/hr = 383.6 mol/hr

383.6 mol HNO_3 requires 1006.95 mol/hr O_2

assume design conditions: tailgas - 2% O_2, 0.4% NO_X
inlet - 31,000 scfm

31000 x 60 ÷ 359 = 5181.1 mol/hr air
5181.1 ÷ 4.76 = 1088.5 mol/hr O_2, 4092.6 mol/hr N_2

4092.6 ÷ 0.976 = 4193.2 mol/hr tailgas

4193.2 x 359 x 0.98 ÷ 60 = 24600 scfm tailgas

NO$_x$ EMISSION DATA

Date 10/19/76

Run No.	1	2	3	4	5	6	7	8
Time	10:30	10:45	11:15	11:30	11:45	12:00	12:15	1:15
µg NO_2	16402	15915	11550	15631	12545	14210	16240	15834
T_i- Initial Flask Temp, ^oR	527	527	527	527	528	528	528	528
T_f- Final Flask Temp, ^oR	537	537	537	537	537	537	537	537
V_{fc}- Flask Volume, ml.	2040	2038	2039	2028	2080	2052	2052	2056
P_i- Initial Flask Pres, "Hg	1.7	1.7	1.7	1.2	1.2	1.19	1.19	1.17
P_f- Final Flask Pres, "Hg	29.33	29.43	28.93	29.28	29.33	29.18	29.88	29.13
lb/scf NO_2 $\times 10^{-4}$	5.52	5.34	3.94	5.20	4.06	4.69	5.23	5.22
lb/10^6Btu NO_2								

$$Vsc = \left(17.71 \frac{^oR}{\text{in. Hg}}\right) \quad (Vfc) \quad \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = \text{scf}$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5} \ \frac{\text{lb/scf}}{\mu\text{g/ml}} \left(\frac{\mu\text{g } NO_2}{Vsc}\right) = \text{lb/scf } NO_2$$

NO_x EMISSION DATA

Date 10/19/76

Run No.	10						
Time	1:30						
µg NO_2	15834						
T_i- Initial Flask Temp, °R	528						
T_f- Final Flask Temp, °R	537						
V_{fc}- Flask Volume, ml.	2057						
P_i- Initial Flask Pres, "Hg	1.17						
P_f- Final Flask Pres, "Hg	28.53						
lb/scf NO_2 $\times 10^{-4}$	5.33						
lb/10^6Btu NO_2							

$$Vsc = \left(17.71 \frac{{}^{o}R}{\text{in. Hg}}\right) \quad (Vfc) \quad \left(\frac{P_f}{T_f} - \frac{P_i}{T_i}\right) = scf$$

$$V_{fc} = V_f - 25$$

$$C = 6.2 \times 10^{-5} \frac{lb/scf}{\mu g/ml} \left(\frac{\mu g\ NO_2}{Vsc}\right) = lb/scf\ NO_2$$

SUPPLEMENTARY PROCESS DATA FOR POWER PLANTS

Date				
Net Unit Load - MW				
Average Steam Load - 10^3 lb/hr				
Boiler Heat Input				
Fuel Burning Rate - lb/hr				
Fuel Heating Value - BTU/lb				
Fuel Sulfur Content - %				
Fuel Ash Content - %				
Fuel Moisture Content %				

Acid Production Rate

Time	Level Gage Pressure, in. Hg.
10	8.5
11	10.1
12	11.8
1	13.4

Power outage
@ 1:45 PM

6.2 tons (100%) acid per in. Hg.

$$\frac{4.9\,(6.2)}{3}(24) = 243 \text{ tons /day}$$

$$\frac{243}{290}(24600) = 20613 \text{ scfm}$$
$$= 1,236,780 \text{ scfh}$$

Operator Samples

Time	% NO_2	% O_2
10	0.43	2.37
12	0.33	2.47
1:30	0.37	2.33

OXIDES OF NITROGEN FIELD DATA

Date 10/19/76

Plant USS AGRI-CHEM

Sample Collected By

Field Data

P_B :			29.70			29.69		29.67
Clock Time	10:30	10:45	11:15	11:30	11:45	12:00	12:15	1:15
Flask number	1	2	3	4	5	6	7	8
Volume of flask (ml)*	2040	2038	2039	2028	2080	2052	2052	2056
Pressure before sampling in. Hg.	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
Pressure after sampling, in. Hg.	29.33	29.43	28.93	29.28	29.33	29.18	29.88	29.13
Flask temperature, °F	67/				68/68			

* Flask + valve - 25 ml. for absorbing solution

1st sample under too much pressure, changed sample method to sampling off the arm of a tee inserted in the sample line.

OXIDES OF NITROGEN FIELD DATA

Date 10/19/76

Plant USS Agri Chem

Sample Collected By

Field Data

Clock Time	1:30							
Flask number	10							
Volume of flask (ml)*	2057							
Pressure before sampling in. Hg.	1.5							
Pressure after sampling, in. Hg.	28.53							
Flask temperature, °F								

* Flask + valve - 25 ml. for absorbing solution